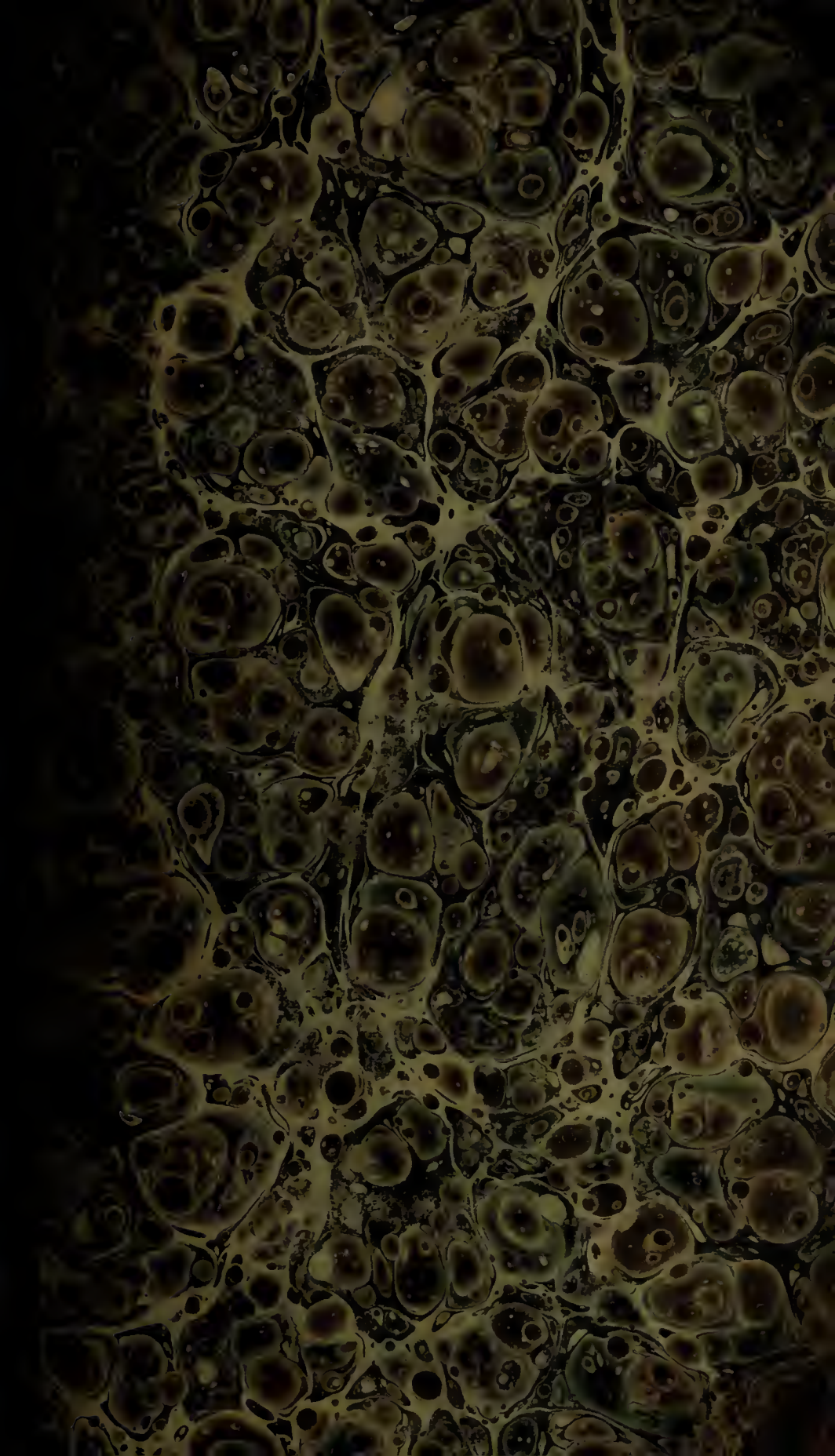




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CHEMISTRY.

Introduction.

THE science of Chemistry, in its most comprehensive sense, is so extensive in its views, that it is necessary to premise a few remarks upon the objects and limits of the following Treatise. All the forms of matter existing upon this earth are capable of being submitted to chemical examination; but this class of investigations carries us even beyond the confines of this globe, and embraces the interesting subjects of light, heat, and electricity. The mere index of a complete system of Chemistry would occupy the space of more than one number of these essays; any detailed examination of so large a field would, therefore, obviously far exceed the range of our present plan. A subject so extensive admits of many subdivisions; these form the objects of separate Treatises, which have been already published, such as Heat, Electricity, Galvanism, Thermometers; or will be hereafter published, as, Animal and Vegetable Chemistry, Crystallography, Chemical Analysis, Metallurgy, Electro-Chemistry, Gaseous Chemistry, &c.

Our object in the present Treatise is to explain the first principles of Chemistry strictly so called; and, in so doing, we shall endeavour, as much as possible, to simplify the subject; and to illustrate it by reference to common experience, or such simple experiments as every one might make with implements and substances commonly to be met with. The study of Chemistry is too often supposed to imply a difficult and abstruse pursuit, and the necessity of a provision of scarce materials and expensive apparatus; and to be adapted only to those who have it in their power to devote themselves entirely to the subject: but we are of opinion that the general principles of the science may be learnt from operations which are constantly going on around us, or which we can command at pleasure; and with which it would highly benefit every one, whatever his station in life, to become acquainted. That so many persons, not uninformed in other respects, should re-

main heedless and ignorant of the constitution of those commonest forms of matter amongst which their lot is cast, and upon which their existence depends, shows an indifference to things of the highest interest, which is irrational; and can be accounted for only by some defect in the common systems of education. Numbers there are, far above the lower classes, who still consider the elements of all things as consisting of Earth, Air, Fire, and Water; an error which classical learning, no less than the expressions of common parlance, tends to perpetuate. Let us hope that the days are at hand, if not already arrived, in which the acquirement of such fundamental knowledge will be looked upon as at least equally necessary with the study of languages, and the cultivation of taste and imagination.

The condensation requisite in this work obliges us to exclude, from the following pages, all historical details; all mention even of the names of those great philosophers by whose labours the science has been built; and all topics of controversy: and we shall confine ourselves to giving a faithful description of the phenomena of nature; pointing out their connexion with each other, and offering the best explanation of their mutual relations, of which the present state of our knowledge allows. Our allotted space will thus be devoted to the more useful portions of the science, while we are compelled to sacrifice much of the interesting and entertaining. But for the sake of those who have the opportunity of pursuing the science further, we shall endeavour to obviate the defects of such a plan, by appending a select list of the best works of reference.

CHAPTER I.

On Attraction and Repulsion, Chemical Affinity and Decomposition.

(§ 1.) ALL the phenomena of the material universe may be ultimately resolved into two kinds of motion; namely, those resulting from the two principles of *attraction* and *repulsion*: in consequence of

which, the particles of matter approach or move from each other according to laws which the intellect of man has been able to develop, but the causes of which appear to be beyond his comprehension. We distinguish two principal modes in which bodies are affected by these opposite forces: in the first, motion is communicated to *masses* (or visible combinations of the ultimate atoms of bodies) at *sensible distances*; in the second, to the ultimate invisible *atoms* of bodies at *insensible distances*. To the former mode belong the attractions of *gravitation*, *electricity*, and *magnetism*; which we see exemplified respectively in the fall of a stone to the earth; the approach of light bodies to resinous substances, or glass, when rubbed; or of iron filings to a loadstone: to the latter may be referred the attraction of *cohesion*; of which we can form a correct idea from the strong adhesion, when pressed together, of the two halves of a leaden bullet which has been cleft asunder; and from the running together of two globules of clean quicksilver, when brought into contact, or of two drops of rain upon a pane of glass. In like manner, *repulsion* at *sensible distances* may be exemplified, by the force with which the particles of glass fly asunder in the common playthings called Prince Rupert's drops; by the flying off of the same light bodies which have been first attracted, after they have been some time in contact with an excited resin or glass, or by the recession from each other of the two similar ends of two magnetised needles: and *repulsion* at *insensible distances*, which is chiefly excited by heat, may be seen in the expansion of the fluid of a thermometer, when warmed by the hand, or the gradual swelling out of a bladder, partly filled with air, before a fire.

Attraction and repulsion, acting upon masses at sensible distances, form the particular study of natural philosophy (in the limited acceptation of the term); which also embraces the same phenomena acting at *insensible distances* upon particles of the *same nature*; as those of the globules of quicksilver, or of the air included in the bladder.

(§ 2.) The study of the effects of attraction and repulsion acting at *insensible distances* upon particles of *different* natures, constitutes the science of chemistry*. The solution of a lump of

sugar, or of alum, in water, is an example of this species of attraction; and the power which determines the union of the sugar, or of the alum, with the water, is specially denominated *chemical affinity*.

(§ 3.) The attraction of cohesion, or that force which unites together particles of the *same* nature, and different modifications of which occasion the variations* of solids and liquids; as well as that power of repulsion, which is opposed to it, and which characterises the state of æriform fluids are, in fact, both opposed to chemical attraction, or the force which combines particles of *different* natures: and common experience daily proves, that a lump of sugar, or crystals of salts, are much more readily dissolved in water, if previously broken down or pounded, than if left in that solid form which the cohesion of their particles imparts. Instances will be hereafter pointed out, which will prove that the strongest chemical affinity may be held in check until cohesion has been destroyed.

The following experiment beautifully illustrates the opposite action of these two attractions:—Place a lump of alum, of a nearly prismatic form, in a glass of water, and carefully watch, from time to time, for some days, the progress of its solution. At first, the water acts with so much energy as to overcome the cohesion of the solid in every direction alike; but as the particles of the alum become united with those of the water, the power of the solvent diminishes; and the lump of alum assumes a pyramidal shape, with the narrow end upwards. The reason of this change of form is, that the particles of water which combine first with the alum become heavier from the union, and fall to the bottom of the glass; and the action at the lower extremity ceases before it is complete at the upper. When the action has nearly terminated, if we closely examine the lump, we shall find it covered with geometrical figures, cut out, as it were, in relief upon the mass; shewing, not only that cohesion resists the power of solution, but that, in the present instance, it resists it more in some directions than in others; and that, when the attraction of the solvent is nearly satisfied, it is balanced by that delicate modification of

* The word chemistry is of Arabic origin, in which language it signifies "the knowledge of the composition of bodies."

* See the Treatise on Heat for an explanation of the cause of vaporization, liquefaction, &c.; and the Treatise on Pneumatics for the mechanical properties of air, &c.

cohesion upon which crystalline arrangement depends. The consideration of the interesting phenomena of crystallization, however, forms one of the necessary subdivisions of our subject, and will be enlarged upon in a separate Treatise, in which the results of the present experiment will be further discussed.

(§ 4.) It will be convenient to distinguish three degrees of chemical attraction;—the result of the first and lowest degree is *mixture*; of the second *solution*; and of the third, and most energetic, *composition*. We shall endeavour to illustrate the distinctive characters of each of these modifications, and also to give a general idea of the various methods of *decomposition* arising from chemical repulsion; and in so doing, we shall hope to present such a preliminary view of affinity, as may assist the further progress of the student. It must, at the same time, be borne in mind, that the developement of the subject can only be found in the full details of chemical science.

On Mixture.

(§ 5.) CHEMICAL mixture can only take place between two bodies when the particles of both are in a like state, and the power of cohesion, with regard to them, so far suspended as to admit of that freedom of motion between themselves upon which fluidity depends: thus, two liquids, or two æriform fluids may admit of mixture; but two solids can be chemically *mixed* only by diminishing their cohesion, by means of heat, to such a degree as to bring them both to the state of liquids.

Between some fluids there appears to be no attraction; and, consequently, they do not admit of mixture: thus, if water and oil be agitated together, they almost immediately separate, and the lighter liquid floats upon the denser. Sulphuric acid, or oil of vitriol, and water, on the contrary, have a strong affinity for each other, and, when mixed together, will not again separate by repose; although one fluid is very much heavier than the other. Alcohol, or pure spirit, and water form a mixture of the like permanent character; and many similar instances might be adduced.

(§ 6.) Of the mixture of æriform bodies we have an example in the atmosphere which we breathe; which consists principally of two species of air mingled together with wonderful uniformity: they have received the names of oxygen and nitrogen gases. They

may be separated, and the latter exhibited in a detached form, by burning a little sulphur in a quantity of the atmosphere confined in a bell glass over water. When this process is performed with care, the oxygen is removed and the nitrogen remains. Of the properties of these bodies this is not the place in which we propose to speak; but we shall only remark, at present, that the residual nitrogen differs so remarkably from the mixture from which it has been separated, as to be fatal to animal life, if breathed, and entirely to extinguish flame. The proportion which it bears to the total quantity upon which the experiment is tried is invariably the same. Unlike the case of liquids, all æriform bodies have the property of mixing together. This difference in the two classes of bodies is to be ascribed to the different modification of the power of attraction between their constituent particles. In the instances where mixture does not take place between two liquids, as oil and water, or quicksilver and water, the still remaining attraction of cohesion between the similar particles is probably greater than the chemical attraction between the dissimilar particles. In æriform fluids attraction of cohesion does not exist, (at least within the limits of common experience,) and the first degree of chemical attraction between the dissimilar particles comes into action unopposed.

The expansive power of heat being opposed to cohesion, the attraction between the particles of some bodies may be so far counteracted by its agency as to reduce them to the fluid state, and then they may admit of mixture: thus melted tin may be mixed with melted lead or copper, and their particles remain intermingled, when from a diminution of temperature they resume the solid state.

(§ 7.) Chemical mixture may take place between two bodies in any proportions. Equal measures of sulphuric acid and water may be mixed together; or one drop of the former with a gallon of the latter; or a drop of the latter with a gallon of the former, or in any intermediate proportions; and in every case the mixture will be perfect, uniform, and permanent. In like manner, oxygen and nitrogen may be mixed in any proportions, although the atmospheric mixture is always constant.

(§ 8.) Chemical mixture between liquids is often attended by condensation or contraction of volume: so that

a measure of sulphuric acid or of alcohol, mixed with an equal measure of water, will not quite fill two measures.

(§ 9.) Increase of temperature is also frequently another concomitant of the mixture of liquids. If four parts, by weight, of sulphuric acid, be suddenly mixed with one of water, at ordinary temperatures, the heat given out will be more than sufficient to make water boil.

(§ 10.) The properties of bodies are not essentially changed by mixture; but those of the resulting product are in some degree intermediate between their component parts: the character, however, of the more active ingredient will predominate, in a degree, of course, proportionate to its quantity. A few drops of sulphuric acid will communicate an intensely sour taste to a quart of water; but the same number of drops of alcohol will scarcely affect the sensible properties of an equal quantity of that fluid.

(§ 11.) The separation of liquid mixtures may be effected by either the addition or subtraction of heat; by the unequal effect produced upon the cohesive attractions of their ingredients. By carefully applying heat to a mixture of alcohol and water, the spirit will rise in vapour and leave the water pure; this process is called *evaporation*, where the elastic fluid is allowed to escape; but when it is separately recondensed and preserved, it is termed *distillation**. On the other hand, by the application of cold to a similar mixture, the cohesion of the particles of water may be so much more increased than that of the particles of the spirit, that the former will separate in a solid form, and leave the latter in a state of purity. It is thus that in the Arctic regions the watery particles of brandy are frozen by exposure to the air, and a very small quantity of strong spirit is left in the fluid state in the interior of the mass.

Mixtures of gaseous fluids cannot be separated by heat or cold, for they all expand in the same degree by equal increases of temperature; but steam and other vapours may be separated from gases by reduction of temperature; for the abstraction of heat destroys the elasticity of the former, but not of the latter. In this manner the aqueous vapour, which is always mixed in a greater or less proportion with the gases of the atmosphere, may be separated; and hence the origin of clouds and fogs.

On Solution.

(§ 12.) SOLUTION is the result of an affinity between bodies in different states with regard to cohesion. In this case liquids are called *solvents*; and they can act upon, or hold in solution, either solids or æriform fluids. We have already alluded to instances of the solution of solids as illustrations of the general subject of affinity (§ 3); and we have shown that the power of cohesion is opposed to this action. Between some liquids and solids there appears to be no attraction whatever; or, if any, it is inferior to the attraction of cohesion by which the homogeneous particles of the solid are united; thus rosin is wholly insoluble in water, but readily unites with alcohol.

(§ 13.) And here we may remark, that chemical attraction, in general, may be exerted in different degrees between one body and several others. There is, as we have seen, a mutual affinity between alcohol and water, whereby they are capable of mixing; there is also a mutual affinity between alcohol and rosin, whereby the former is capable of dissolving the latter; and there is no affinity between water and rosin. Now if, to a solution of rosin in alcohol, water be added, it will be found that the rosin will resume the solid form: the attraction between the particles of alcohol and those of water, is greater than between the particles of alcohol and those of rosin; the consequence is, that the alcohol quits the rosin, and combines with the water, and the attraction of cohesion being no longer opposed, resumes its ascendancy. This has been called *elective attraction*, because the alcohol may figuratively be said to exercise a choice between the substances with which it is capable of combining. This resumption of the solid form of a substance, previously dissolved in a liquid, is termed *precipitation*; although the term can only be strictly applied where the solid, set at liberty, falls to the bottom of the vessel.

(§ 14.) Unlike the case of mixture, there is a limit to the power of solution; and liquids cannot combine with more than a certain definite quantity of any solid or æriform body: thus water will only take up a certain known weight of alum, or alcohol of rosin. The point at which the action between the two bodies ceases, is called the point of *saturation*. Up to this point the two bodies may combine in any proportions.

* See the Treatise on HEAT for an explanation of the general principles of evaporation, distillation, &c.

Carbonic acid, or that æriform substance, formerly known by the name of *fixed air*, which most persons are acquainted with, as given off from bottled beer or soda water, is capable of being absorbed by water; which liquid, under ordinary circumstances, will take up rather more than its own bulk of this air (or gas). As in the case of solids, the attractive power of cohesion, at a certain point, balances the action of the solvent, so, in æriform bodies, the repulsive power of elasticity sets similar limits to its exertion. It is only to a certain point that the solvent power of water can counteract the elasticity of the carbonic acid; and beyond this point of saturation it cannot unite with it.

(§ 15.) The influence of heat upon the power of solution, corresponds with the difference between cohesion and elasticity. Upon solid bodies it generally *increases* the power of the solvent, by diminishing their *cohesion*. Upon æriform bodies it *diminishes* the power, by adding to their *elasticity*. Water may be saturated with alum at the common temperature of the atmosphere, and if heat be afterwards applied, will dissolve an additional quantity; if the solution be then allowed to cool, the attraction of cohesion will resume its ascendancy, and the second portion of the alum will be deposited in solid and regular forms. If, on the contrary, a saturated solution of carbonic acid in water be heated, the gas will escape from its combination; for the heat increases the repulsive power of the particles of the gas, and the affinity of the solvent is no longer able to counteract it.

(§ 16.) A solvent that has been saturated with one substance, is often capable of combining at the same time with others; thus water which has taken up its full proportion of saltpetre, will further dissolve a considerable quantity of common salt.

(§ 17.) The process of the solution of a solid in a liquid, is very frequently accompanied by a diminution of temperature; and great degrees of cold may be produced by dissolving certain proportions of different salts in water. A reduction of 17° is produced, by merely saturating water at common temperatures with nitre; and nitrate of ammonia will, in the same way, lower the thermometer from 50° to 4° . The solution of gases, on the contrary, is generally accompanied by the production of heat.

* See Treatise on HEAT, p. 59.

(§ 18.) The properties of bodies are not changed by solution any more than by mixture; and the characters of such combinations are intermediate between those of their ingredients. The most universal solvent in nature is water; and as the characters of that liquid are very neutral, *i. e.* distinguished by no very energetic or active properties, aqueous solutions, in general, possess in an eminent degree the properties of the solids or gases with which they are combined.

(§ 19.) Solvents may be separated from the bodies with which they are united by alterations of temperature, which change their state of cohesion. If a solution of alum be strongly heated, or boiled, the liquid will assume the state of vapour, or of an elastic fluid, and flying off, the solid will remain. If a solution of carbonic acid in water be frozen, the gas will escape, and the water remain in the solid state. The affinities, however, of some gases for water are so strong, that they rise in union with its vapour, and cannot be separated by evaporation.

Chemical Composition.

(§ 20.) COMPOSITION is the result of the highest degree of chemical attraction; which may take effect between bodies whose particles are under every modification of cohesive attraction. The attractive force, however, of cohesion, as well as the repulsive power of elasticity, are in various degrees opposed even to this power; and till reduced or modified, often prevent its action altogether. The state of liquidity is consequently most favourable to its efficiency.

(§ 21.) The union of bodies in this intimate manner only takes place in *definite proportions*, which are invariable in the same compound, and it is commonly accompanied by a total change of their sensible properties. Great alterations of temperature almost always accompany the act of combination; and when the action is most energetic, light and heat are given off in abundance, and often with violence.

If copper filings and sulphur be mechanically mixed together, they will exhibit no tendency to unite at the common temperature of the atmosphere; but if heat be applied, as soon as the latter melts, a violent action will take place; the copper will become red hot, and a black, brittle body will be produced, with properties totally different from

those of its two ingredients. This compound is often found ready formed in mineral veins; but whether the product of nature or of art, as above described, its composition is definite and invariable; and it is found to consist of 64 parts of copper to 16 parts of sulphur: or 100 parts contain 80 copper and 20 sulphur. Our reason for preferring the statement of the proportion in the former numbers will hereafter appear.

(§ 22.) It often happens, however, that a body will unite in this manner in more than one proportion with another; the composition in each case being no less definite and fixed: but the proportion of one of the ingredients of the resulting compound is always some multiple or sub-multiple of that in the first compound; that is to say, it is double or treble, or half, and so on. Thus a second combination of copper and sulphur is known, which, although it cannot be produced by the direct union of the two bodies, is of very common occurrence, and constitutes the important ore from which nearly all the copper of commerce is derived. The proportions of this compound are 64 copper to 32 sulphur; that is to say, the copper is combined with exactly double the proportion of sulphur which exists in the first combination.

(§ 23.) The compounds which mercury or quicksilver forms with some other bodies, are well calculated to exhibit the striking difference of character which are the results, not only of chemical composition, but of composition in different proportions. If this brilliant, white, fluid metal be agitated for a long time in contact with the common air, it will unite with the oxygen of that mixture, and will be converted into a black, insipid, insoluble powder; which consists of 200 parts of mercury to 8 of oxygen. If, instead of being agitated at common temperatures with the air, it be kept heated with it to nearly its boiling point, it will be converted into a red, shining mass, also a compound of the metal and oxygen; but which is endued with an acrid, metallic taste, is soluble in water, and poisonous. It consists of 200 parts of mercury, and 16 of oxygen.

Mercury also combines with sulphur in two proportions: by long-continued trituration (or rubbing in a mortar) the two bodies unite, and form a black, tasteless compound, which contains 200 parts of mercury to 16 of sulphur.

If mercury be poured into melted sul-

phur, and strongly heated, a compound will be formed, which rises in vapour, and concretes, on cooling, into a brilliant red substance, known by the name of cinnabar or vermilion. It is composed of 200 parts of mercury, and 32 of sulphur.

Again, the well-known medicine called *calomel*, is a compound of mercury, and an æriform substance, which we shall hereafter describe, called chlorine. This compound is white, crystalline, very heavy, tasteless, and nearly insoluble in water. It may be taken in doses of several grains without any effect, but that of a purgative. It is composed of 200 parts of the metal, and 36 parts of chlorine.

Mercury is capable of combining with a further proportion of the same gaseous body; in which case it is converted into a semitransparent, white mass, of an acrid, nauseous, metallic taste, soluble in water and alcohol, and highly poisonous. It is well known by the name of *corrosive sublimate*, and is composed of 200 parts of mercury, and 72 parts of chlorine.

Thus substances, comparatively inert, may produce, by their union, compounds of highly active properties; and a compound of two bodies, which, in one fixed proportion will, if taken internally, have but a slight effect upon the animal frame, if united in a different proportion, will prove destructive to life.

(§ 24.) Highly active bodies of opposite properties will also produce by their combination substances of mild character, and they are then said to neutralize each other.

Sulphuric acid, or oil of vitriol, to which we have before referred as a well-known liquid, for the purpose of illustrating the nature of chemical mixture, is highly corrosive, and possesses an intensely sour taste. If brought into contact with a substance stained with the delicate colour of any blue vegetable, such as that of violets or litmus, it instantly changes its tint to bright red; a property which belongs to all acids.

There is another substance, also well known, and commonly to be met with, called *Barilla*, or carbonate of soda. It is a solid, soluble in water, of a hot, acrid, bitter taste. It changes the blue colour of vegetables to green; a property which belongs to a class of bodies denominated alkalies. Between these two bodies a strong affinity subsists. If into a solution of the latter we carefully drop

a portion of the former, a brisk effervescence will ensue, and carbonic acid, or fixed air, will be given off, as from soda water. If the experiment be performed with care, and the dropping in of the acid stopped, the moment the effervescence ceases, the solution will be found to be warm, and to be possessed of properties totally different from those of the acid and the alkali from which it has been formed. It will not be sour, corrosive, acrid, nor hot. It will have no action upon blue vegetable colours, and all the active properties of the original bodies are said to be *neutralized*—they have *neutralized* one another. The product is slightly bitter, saline, and cooling. If part of the water be driven off by heat (or evaporated), a solid will be deposited in regular forms, which was previously held in solution by the water which escapes. This substance is known by the name of Glauber's salt, or sulphate of soda, and is extensively used in medicine.

(§ 25.) That power of affinity which produces chemical composition may, as in the case of solution, (§ 13) exist in a body in different degrees towards other bodies; and if to a compound of two bodies a third be presented which has a stronger attraction for either of the two ingredients than they have for each other, decomposition of the original compound will take place, and a new compound will result. Barilla, or carbonate of soda, to which we have just referred, is a compound of a highly caustic, alkaline substance, called soda and carbonic acid. In the experiment above alluded to it is decomposed; the sulphuric acid expels the carbonic acid, which escapes in effervescence, and takes its place with the soda. If a solution of this substance in water be boiled with caustic lime, the carbonate of soda will be decomposed, the carbonic acid will quit the soda and unite with the lime and carbonate of lime, or chalk, and caustic soda will be the result. This action is called, for the reason already explained, *single elective affinity*.

(§ 26.) If two compounds be brought together in solution, it will not unfrequently happen that a process of double decomposition and composition will take place, from a new adjustment of the various affinities: that is to say, the two original bodies will be decomposed, and two new compounds produced, from a mutual exchange of ingredients.

The substance known by the name of

sugar of lead, is a compound of vinegar, or acetic acid and lead. *White vitriol* is composed of sulphuric acid and zinc. Now if, in a solution of the former substance in water, we suspend a piece of metallic zinc, we shall have an example of *single elective affinity*. The attraction of vinegar for zinc is greater than for lead; the acid will therefore abandon the lead, which will resume its metallic form, and unite with the zinc. The experiment is very beautiful as the lead is precipitated upon the zinc in an arborescent form. But if a solution of acetate of lead be mixed with a solution of sulphate of zinc, the acetic acid will, as before, abandon the lead to unite with the zinc; but at the same moment, the sulphuric acid will attract the lead, and form with it an insoluble compound, which will be precipitated in the form of a heavy white powder. This compound action has been distinguished by the name of *double elective affinity*. Decompositions which cannot be effected by *single elective affinity* may often be produced by *double elective affinity*.

(§ 27.) Now we may remark, that the same quantity of acetic acid which originally was combined with the lead, is exactly sufficient to enter into combination with the zinc; and also that the same quantity of sulphuric acid which entered into composition with the zinc, exactly suffices for the lead: none of the ingredients are found in excess, and the proportions of each are *equivalent* to each other in their power of combining. This observation exemplifies another fundamental law of chemical *composition*; namely, that bodies not only combine together in proportions which are fixed with regard to each other, in any given compound, but are also *definite* with regard to every other substance with which they are capable of entering into composition; so that there are certain determinate proportions of all bodies which are *equivalent* to each other in their powers of combining with all other bodies. Thus sugar of lead, or acetate of lead, is a compound of 50 parts of acetic acid and 112 parts of lead in the state (which will be hereafter explained) of an oxide. White vitriol, or sulphate of zinc, is composed of 40 parts of sulphuric acid, and 41 parts of zinc, also in the state of oxide. Now these proportions are all *equivalent* to one another; and if we write their numbers against the different substances as follows, we can at once perceive the proportions in

which they will unite in any new combination.

Sulphuric acid . . .	40
Zinc (oxide) . . .	41
Acetic acid . . .	50
Lead (oxide) . . .	112

Thus, from such a table we may anticipate, in the double decomposition above referred to, that the white powder or new compound of sulphuric acid, and lead, precipitated, must consist of 40 parts of the former and 112 of the latter; and likewise that the combination of zinc and acetic acid, left in solution, must be in the proportion of 50 parts of acid and 41 parts of zinc: and this exactly agrees with the results of experiment. We shall hereafter find that the same equivalent numbers, or their multiples, are preserved in every possible combination with other bodies; and that similar numbers may be attached to all the known substances of the chemical catalogue. Moreover, when any body is compounded of two simple substances and enters into combination with another body, the sum of the equivalents of the two elements will give the number, denoting the proportion in which it will so combine. Having endeavoured to convey a general idea of this universal law of chemical composition, it does not enter into our plan to pursue the subject further in this place: its full development will only be found in the complete body of chemical facts.

(§ 28.) The attraction of cohesion is opposed to the highest degree of chemical attraction in the same way as to the inferior degrees. Barilla or carbonate of soda is capable of acting strongly upon pounded flint, and produces, by its combination with it, the well-known substance, crown glass: but before the attraction of cohesion in the flint is diminished by pounding, the chemical affinity between them is not efficient.

(§ 29.) The minor degree of affinity by which solution is effected has also a strong influence over the power of composition. It acts chiefly by counteracting cohesion and repulsion, and thus bringing the particles of solids and æriform fluids within the sphere of mutual action.

Sugar of lead and white vitriol, in their solid forms, have no action upon each other; but balance their powers of cohesion by dissolving them in water, and the double elective affinity is immediately at liberty to act in the way which we have pointed out (§ 26.)

(§ 30.) There is another circumstance, mechanical in its nature, and the influence of which is somewhat obscure, which sometimes interferes with *chemical composition*; that is, *quantity*: for, in comparing the attraction of two bodies for a third, a weaker affinity in one of the two is found to be compensated by increasing its quantity. If one part of common salt (which may be considered as composed of muriatic acid and soda) be mechanically mixed with half its weight of red lead (oxide of lead) and water, to the consistency of a thin paste, no decomposition of the salt will ensue: the soda has a stronger attraction for the acid than the oxide of lead. If, however, the weight of the red lead be increased to three or four times that of the salt, after standing some time, the strong taste of the soda will be perceptible; proving that the larger quantity of the oxide has the power of detaching a considerable portion of muriatic acid from the soda, notwithstanding the stronger affinity.

(§ 31.) The influence of temperature upon the highest degree of chemical attraction, is various: sometimes it favors its operation by counteracting the cohesion of solids; sometimes it opposes it by increasing the repulsion of æriform fluids. An increase of heat frequently increases directly the energy of affinity, and determines combinations which would not otherwise take effect; and different degrees of temperature often produce opposite effects.

We have shewn that, by raising the temperature of quicksilver or mercury to nearly its boiling point, a combination is determined between it and oxygen, one of the mixed gases of the atmosphere: if this compound be more strongly heated still, it will be decomposed, and oxygen and the metal will be reproduced.

If a spirit lamp be supplied with ether instead of alcohol, it will inflame upon approaching to it a body in a state of inflammation; but if instead of a body of so high a degree of heat a coil of platina wire, heated to redness, be laid upon the wick, the ether will still be consumed, and the wire will continue to glow, but no flame will be produced. The products of these two species of combustion will be totally different, and each is determined by the degree of temperature at first communicated, and which is maintained without variation, by the heat evolved in each process.

On Chemical Decomposition.

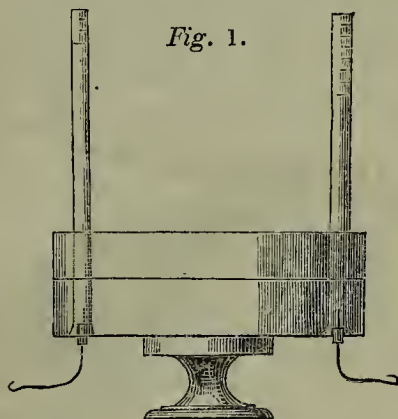
(§ 32.) WE have seen how *chemical decomposition* may be effected by *elective affinity*, or the superior chemical attraction of one of two combined bodies for a third; and we have also seen that such decomposition may be brought about, in some cases, directly by the agency of heat. The agency of the voltaic pile is however the most general and effectual known in disengaging substances of different natures from their combinations with each other. Such a degree of repulsion may be communicated by means of electricity, to the ultimate particles of matter of unlike kinds, as entirely to counteract the strongest chemical attraction between them; and bodies which resist this powerful agent of decomposition are deemed *simple* or *elementary*. Of the *cause* of this repulsion we know no more than we do of the nature of attraction: its *effect* may be understood from the following experiment.

Place a few drops of a saturated solution of Glauber's salt (sulphate of soda) upon a piece of paper stained with the blue colour of litmus; and also a few drops of the same solution upon another piece stained with the yellow colour of turmeric: connect the two portions of the solution by a few filaments of moist cotton, and place the positive wire of an active voltaic pile in contact with that on the litmus paper, and the negative wire with that on the turmeric paper. In a short time the litmus paper will exhibit a bright red, and the turmeric paper a deep brown stain; the former being the indication of the presence of an acid, and the latter of an alkali. It will be recollected that we have described (§ 23) the composition of Glauber's salt from the action of affinity between sulphuric acid and carbonate of soda: by the decomposing action of the pile these are again disjoined; and the soda appears at the negative and the sulphuric acid at the positive wire of the apparatus. This decomposition may be effected by a comparatively small power of electric action; and a pile of fifty pairs of copper and zinc plates suffice for the purpose.

If soda, one of the products of the last experiment, be subjected to the action of a more powerful pile, a further decomposition will take place; an elastic fluid, oxygen, will be given off at the positive wire, and a substance, endued with metallic lustre, will collect around the negative wire. This is the metal sodium: it

is not susceptible of further decomposition, by the application of any power with which we are acquainted; and is, therefore, ranked with the simple substances. When the action of the pile is discontinued, it again rapidly attracts oxygen from the atmosphere, and is reconverted into soda. Sulphuric acid, the other product of the decomposition of the salt, may also be resolved into its elements by the same agency; in which case sulphur will collect at the negative pole, and oxygen be given off at the positive. These experiments will only succeed with a powerful voltaic apparatus, such as it is not easy to meet with.

We shall give another instance of decomposition, which may be produced by the moderate electric power previously referred to. Let the two wires of the voltaic pile, which for this purpose ought to be of platinum, be immersed in a vessel of pure water: the liquid will be decomposed; gaseous matter will be given off from each wire, but of very different properties, at the opposite extremities. It may be collected, by inverting glass tubes, closed at one end, and filled with water, over the wires, *fig.* 1. The elastic fluids will rise into the



tubes, and displace the water. The quantity collected over the negative wire will be double in volume to that collected over the positive wire. If a splinter of lighted wood be plunged into the first (which may be done by dextrously inverting the tube, and keeping the open end closed with a finger, till the flame be introduced), it will be instantly extinguished, but the gas itself will inflame at the surface. If into the second a splinter of wood, which, after being inflamed, has been extinguished, but still preserves

a glowing point, be immersed, it will be instantly rekindled, and burn with great brilliancy; but the gas itself will not take fire. To the former elastic fluid the name of hydrogen has been given; the latter is oxygen. These two bodies are the elements of water; and, not being capable of further decomposition, in the present state of our knowledge, are reckoned simple substances*.

(§ 33.) The peculiar mode of decomposition arising from *electrical repulsion* has afforded a basis for an artificial arrangement of the simple substances for the convenience of study; and by its means they are divided into two classes. The first consists of those elements which are attracted from their compounds with substances of the other class, by the positive pole of the voltaic pile; and as bodies in opposite states of electrical action attract one another, they may be called *electro negative* bodies.

The second comprises those elements which are attracted by the negative pole from similar combinations, and for the same reason may be distinguished as *electro positive* bodies. But this difference of electrical energies must be considered, in a great measure, as comparative; for in any compound of two bodies of the same class, for instance of the electro negative, one will be less electro negative than the other, and will consequently pass to the negative pole in the act of decomposition.

The elementary substances at present known do not amount to more than between fifty and sixty, and of this small number is all the beautiful variety of terrestrial matter composed! and what is still more wonderful! a very small proportion only of this small number enter into the composition of those objects of infinite diversity which are most familiar to our senses; and many of them are of such rare occurrence, and in the present state of our knowledge apparently of so little importance in the frame of creation, that the sole purpose of their formation would almost appear to have been a display of that infinite Power, by which all things were produced, for the admiration and gratification of the diligent inquirer, and a stimulus to his pursuits.

(§ 34.) There are four simple substances which exist in the gaseous state under the common circumstances of at-

mospheric temperature and pressure; these are oxygen, chlorine, hydrogen, and nitrogen. The first two belong to the *electro negative* class, and the last two to the *electro positive*.

Of these bodies, and of their combinations with each other, we shall proceed to give some account; but not in the order in which they stand above, as by departing from it in this instance, we shall have the advantage of treating, first, of the properties of some compounds which are every where presented to our observation; instead of commencing with others which are of rare occurrence, not easily produced, and not so perfectly understood. This will greatly facilitate the comprehension of the subject, and will amply compensate for any defect of arrangement.

CHAPTER II.

On the Gaseous Elements—Oxygen, Chlorine, Hydrogen, and Nitrogen, and their Combinations with each other.

*On Oxygen**.—8.

(§ 35.) BEFORE we proceed to shew how oxygen gas may be obtained, it will be necessary to premise a few words upon the method of collecting and examining æriform bodies. It is foreign to the design of this treatise, as we have before stated, to enter into the niceties of chemical operations, or to describe all the beautiful contrivances which ingenuity has introduced into chemical apparatus, for ensuring the utmost accuracy in delicate experiments. Although such inventions are highly useful, and even necessary, in carrying on original investigations, they are by no means required for obtaining that general idea of the laws of chemistry which every one ought to possess, for the proper understanding of the commonest concerns of life, and which may be sufficiently illustrated by every day occurrences, and easy experiments. In the way of apparatus, wine and beer glasses, of various sizes; apothecaries' phials; thin oil flasks, well cleaned; with glass and tin tubes of various dimensions; old gun barrels; tobacco pipes; an argand and a spirit lamp, with a common fire and bellows, offer almost inexhaustible resources to a

* For a further exposition of this subject, see the Treatise on GALVANISM.

* Derived from two Greek words signifying "the formation of acids," as oxygen enters into the composition of a large majority of the acids, and was formerly supposed to be the general acidifying principle.

person endued with the faculty of contrivance; especially if he make himself master of the very easy art of sealing, bending, and enlarging a glass tube over a lamp.

For the collection of gases, sparingly soluble in water, a white earthenware foot-bath, or a small washing-tub, (*fig. 2.*) may be employed. In this a shelf should

be fixed, or a metallic trivet stand, in such a way as that, when the bath is nearly filled with water, it may flow two or three inches above its surface. Glass jars, bell glasses, tubes, or bottles, may be filled with water by reclining them in the open part, and may afterwards be placed upon the shelf with their mouths downwards. A glass, or metallic tube,

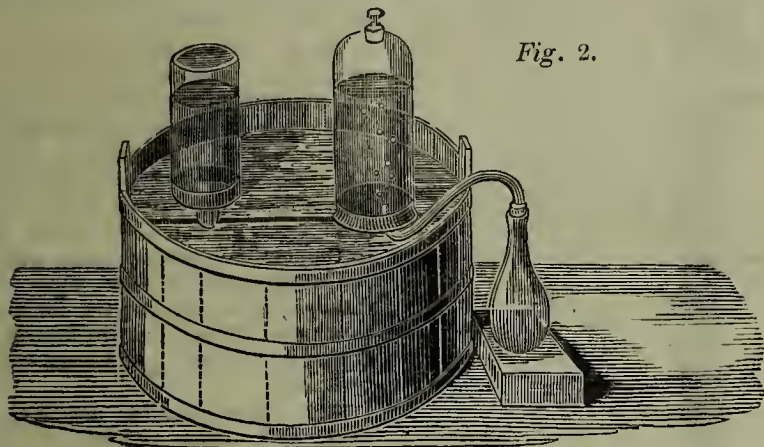


Fig. 2.

proceeding from the vessel containing the substances from which the æriform fluid is emitted, may then be laid under the edge of the jar, which, for this purpose, is permitted to project a little over the shelf; the gas will then rise into it in bubbles, and gradually displace the water. A gas may also be readily transferred from one vessel to another, by carefully reclining the glass which contains it under the edge of another filled with water, and projecting over the shelf; and they may likewise be removed from the bath, and transported from one place to another, by placing them in shallow vessels or saucers, and surrounding them with about an inch of water. These operations are simple and easy; but no one should be disappointed in not succeeding in their performance, without some practice and perseverance.

(§ 36.) We have seen that when the metal quicksilver (or mercury) is submitted for a considerable time, in communication with the atmosphere, to the action of heat near its boiling point, it is converted into a brilliant red substance, which was formerly known to druggists by the name of *precipitate, per se*. In this operation the mercury increases its weight about 8 per cent.

The metal lead exposed to a strong heat with a large surface, and a free access of air, is also converted into a

bright red substance, commonly known by the name of *minium*, or red lead.

Both these substances, when exposed to a red heat, give out the oxygen, which they had previously attracted from the air at a lower temperature; this operation may be performed in a retort, or glass tube, (*fig. 3.*) sealed at one end, a

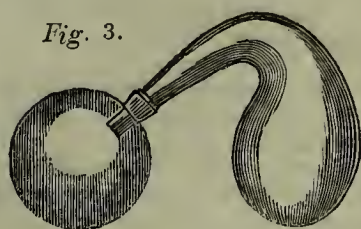


Fig. 3.

little extended by blowing into it, and bent at an angle, the heat should be gradually applied. For the production of the gas, the small, open end of the retort should be placed under the edge of a vessel filled with water in the water-bath: in the figure it is represented as connected with a receiver for the purpose of distillation. Oxygen gas may, however, be better obtained for examination from a salt known by the name of Chlorate of Potash. This may be placed in a glass tube, with one end closed, and the other fitted with a cork, into which a smaller pipe is inserted, bent

at a right angle, (*fig. 4.*) and laid under the edge of a jar filled with water, on the shelf of the water-bath. When heat is applied, by means of a lamp, to this substance, it fuses, and gives out

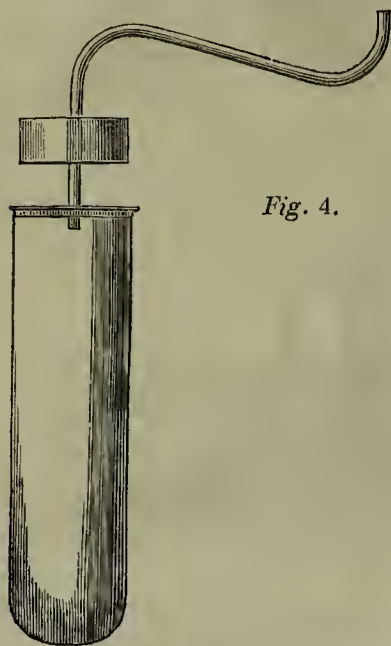


Fig. 4.

the gas in great purity. It may also be procured from saltpetre, or a substance known by the name of black oxide of manganese, strongly heated in a gun-barrel, with the touch-hole plugged up, and from which a small pipe of tin, or other substance, fitted to it, is laid under the jar. In collecting gases of any kind, the first portions should be always set aside as impure, as they are mingled with the common air which the apparatus necessarily contains.

Oxygen gas may also be collected in small quantities from growing vegetables, exposed to the solar light, or from the green matter which forms in stagnant pools, by immersing them in a bell glass filled with water.

(§ 37.) Oxygen gas is colourless, without smell or taste, and may be breathed with impunity for a considerable time; but in its pure state is ultimately found injurious to animal life. It is not dissolved by water, except in very minute quantities. It is rather heavier than atmospheric air; 100 cubic inches of the latter weighing 30.5 grains, and of the former about 3 grains more or 33.8.

(§ 38.) We will here explain, once for all, that in speaking of the weight of gases, we shall always suppose the baro-

meter to stand at 30 inches, and the thermometer at 60°. Those who wish to know how they are affected by variations of temperature and pressure, and in what way corrections can be applied for such variations, must consult the treatise on *Gaseous Chemistry*, where these points will be explained, together with such minute details of manipulation as it does not enter into our present purpose to describe.

(§ 39.) All combustible bodies burn in oxygen with increased splendor. If the glass which contains it be furnished at the top with a stopper, it will be easy to prove this by introducing substances in different states of ignition. They may conveniently be attached to a wire passing through a cork which is made to replace the stopper when withdrawn. A small piece of wax taper, with its flame blown out, but its snuff still red hot, upon being let down into it, will be instantly rekindled, and burn with great brilliancy.

A piece of charcoal attached to the wire, and made red-hot, burns most vividly, throwing out beautiful sparks.

If the wire which passes through the cork be made to terminate in a small spoon, (*fig. 5.*) a small piece of sulphur or phosphorus may be placed in it and kindled; they will burn in the gas with a splendor which the eye cannot bear.

Fig. 5.



Twist some thin iron wire into a spiral form round a slender rod, which must then be withdrawn; let the end be dipped in melted sulphur and ignited; when let down into the gas, the iron will burn with a brilliant light, and scintillate like a firework.

If such a glass jar and stopper, as we have described, should not be at hand, these experiments may be performed in a common bottle, into the neck of which the cork and wire may be loosely inserted, and which it will not be found difficult, with the assistance of a small funnel, to fill with gas over the water-bath.

The above are all instances of intense chemical affinity, during the action of which light and heat are given off in abundance. During the various processes the oxygen will disappear, and the substances with which it combines will proportionally increase in weight. It is not difficult to prove these facts in

a general manner; but to perform the experiments with precision requires a complicated apparatus.

Coil up a known weight of iron wire, and place it in the bowl of a tobacco-pipe, the pipe of which is connected with a bladder filled with oxygen gas; heat the wire to redness in the fire, and then force through it a stream of the gas from the bladder. The iron-wire will burn; that is to say, it will combine with the oxygen, and from the intensity of the action light and heat will be emitted. When weighed, it will be found to be considerably heavier than before, and 100 grains will have increased to about 130.

Oxygen is electro-negative with regard to every other known body, and is attracted by the positive pole of the Voltaic pile from all its combinations, even with substances of its own class.

On Hydrogen.—1.*

(§ 40.) If, into a bottle, containing filings or turnings of iron, or zinc, we pour sulphuric acid, diluted with six or seven times its weight of water, a strong action will take place, and a gas will be given off, which may be collected in the manner before described, by means of a bent tube, fitted to the mouth of the bottle with a cork. This is Hydrogen gas.

(§ 41.) It is colourless, and without taste; but, as commonly prepared, has a faint disagreeable smell; which, however, is supposed to depend upon some slight impurity. It is speedily fatal to animal life when taken into the lungs. It is not absorbed by water except in very minute quantities. It is lighter than atmospheric air; and, indeed, the lightest of all bodies which are known to possess weight; 100 cubic inches only weigh 2.1 grains. If a bladder be filled with it, and attached, by means of a stop-cock, to a tobacco pipe, upon dipping the bowl into a strong lather of soap, bubbles may be blown with it which will rise rapidly into the air; and it is upon this principle that it is used for filling air-balloons. It is inflammable, but it extinguishes flame.

Fill an inverted stoppered bottle with the gas, and close it with the stopper. Fix a small piece of wax-taper upon a wire, and ignite it; turn the bottle up, remove the stopper, and carefully introduce the taper. The gas will imme-

diately inflame at the mouth of the bottle; but the flame of the taper immersed in the gas will be extinguished. Upon withdrawing the taper it may be rekindled as it passes through the flame of the gas, and again extinguished by returning it.

If a mixture of two parts of common air, and one of hydrogen, be made in a strong phial, capable of containing about four ounces of water, it will inflame upon presenting a candle to it, not silently, as in the last experiment, but suddenly, and with a loud explosion. The bottle should be wrapped round with a cloth to prevent accidents, in case it should burst in the experiment.

(§ 42.) Oxygen and Hydrogen gases may be *mixed* together in any proportions; and their disposition to become equally diffused in any given volumes, as with all gases, is so great, that even the vast difference in their specific gravities will not keep them separate.

Fit two glass phials with corks, into which a glass tube may be inserted ten or twelve inches long, and about one-twentieth of an inch bore. Fill one of the phials with oxygen, and the other with hydrogen. Place the former with its mouth upwards upon a table, and insert the cork with the tube; fit the cork into the latter, and fix it upon the other end of the tube with its mouth downwards. The hydrogen will descend and the oxygen ascend, notwithstanding the former is sixteen times lighter than the latter; and if they be permitted to remain two or three hours in the perpendicular position described, upon applying a light to either phial an explosion will take place.

(§ 43.) This explosion, which in the above experiment testifies the mixture of the two gases, is produced by the sudden exertion of that higher degree of affinity between the two gases, which gives rise to *composition*, and which is brought into action by the high temperature of flame. The compound in this instance is *water*.

The composition of water may be demonstrated by *synthesis* (which means the formation of any body from its elements), and by *analysis* (the resolution of a body into its component parts). Eight parts by weight of oxygen combine with one part of hydrogen to form water.

(§ 44.) Now, as hydrogen is the lightest known body in nature, and combines in the smallest proportion by weight, with

* From two Greek words, signifying "the formation of water," as it enters largely into the formation of that liquid.

the other simple substances, it is convenient to assume it as the standard of comparison for the combining proportions, or *equivalent numbers* of all other bodies; which, moreover, it is highly probable are simple multiples of its number. Hydrogen, therefore, thus standing at the head of the scale, and being represented by 1, the equivalent of oxygen will be 8, and that of water 9.

Oxygen, however, is sometimes assumed as the standard of comparison, and represented by the number 10, in which case the equivalent for hydrogen is 1.25; the result is of course the same, the proportion of 1.25 to 10 being the same as that of 1 to 8. The choice is one of convenience, and on this account we prefer the former.

We shall, in the course of this treatise, attach to the name of each substance, placed at the heads of the sections, its simple number upon this scale of equivalents; it is of the greatest importance to impress them strongly upon the memory, and they will thus be perpetually presented to the eye in a prominent manner. Where the body is compound, we shall also affix the proportions of the elements of which it is compound.

(§ 45.) The composition of elastic fluids develops a still more simple law of combination in this class of bodies, than that of *definite weights*; it is that of *definite volumes*. The union of gases is always effected in simple proportions of their volumes; and a volume of one gas combines with an equal volume, or twice or three times the volume of another gas, and in no intermediate proportion.

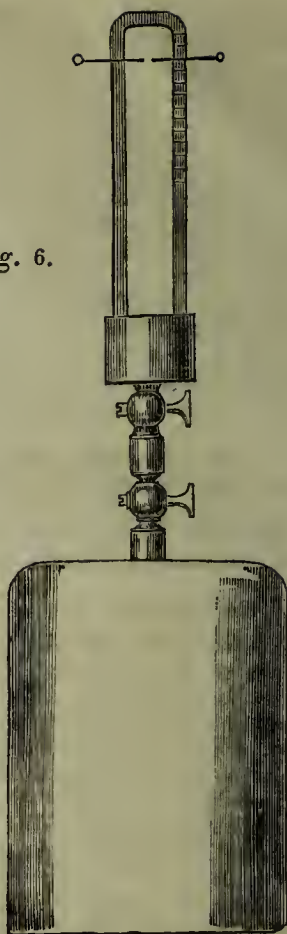
On Water.—9, (1 O. 8 + 1 H. 1).

(§ 46.) OXYGEN and hydrogen combine in the proportion of one volume of the former, to two of the latter, to form water.

The experiment is one of some nicety, but may be performed in the following way.

Provide a very strong glass tube, (*fig. 6.*) closed at one end, and fitted at the other with a brass cap and stop-cock, strongly fixed with cement. Two small holes must be drilled in the upper part of this tube, into which two wires must be cemented, the points of which must nearly touch one another on the inside. Let a mixture of very pure oxygen and hydrogen gases be very accurately made, in the proportions named above, in a jar fitted with a stop cock, to which the

Fig. 6.



cock of the tube may be connected. Extract the air from the tube by means of an exhausting syringe, screw it on to the jar, and upon opening the cocks a portion of the mixture will rush in. Again exhaust the tube to secure the extraction of any remaining air. Replace it upon the jar, fill it again with the mixture, and carefully close the stop-cocks. Pass an electric spark through the wires, and the gases in the tube will explode. Allow the tube to cool, and upon opening the cocks a fresh portion of the gases will rush in, which will be equal to the first quantity, provided the mixture has been accurately made, and the common air perfectly extracted. This portion may be again inflamed, and the process continued, till a strong dew is seen upon the interior of the tube. This, upon examination, will be found to be pure water.

If the mixture be made in any other proportion than that of one of oxygen to two of hydrogen, the excess of either gas

will be left, for they will combine in no other. Those who have not the means of repeating this experiment, may convince themselves that the product of the combustion of hydrogen gas in oxygen is water, by burning a small stream of hydrogen from a bladder, under a bell-glass, with atmospheric air. As the combustion, i. e. the combination of oxygen and hydrogen, proceeds, water will condense upon the cold surface of the glass, and trickle down its sides.

(§ 47.) We have already adverted to the *analysis* of water by means of the voltaic pile (§ 32); it is in perfect accordance with its *synthesis*, and when both these processes agree in their results, the demonstration is the most perfect of which chemical philosophy is capable. The hydrogen given off at the negative pole is exactly the double in volume of the oxygen given off at the positive pole.

Water may also be decomposed, by means of heat and elective affinity, in the following way:—Take a gun-barrel, the breech of which has been removed, and fill it with iron-wire coiled up. Place it across a common chafing dish, and connect to one end of it a small glass retort containing some water; and to the other a bent tube, opening under the shelf of the water bath. Heat the barrel red hot, by means of charcoal, and apply a lamp under the retort. The steam of water, in passing over the red hot iron, will be decomposed, the oxygen will unite with the iron, and the hydrogen may be collected in the form of gas. This is the most economical way of making hydrogen in large quantities. Those who have an opportunity of visiting an ironfoundry, may see this process constantly going on; for when the melted metal is poured into the damp moulds, the water which they contain is decomposed, and the hydrogen which is given off is ignited; and generally, from its mixture with the air, produces a slight explosion.

If this experiment be made very carefully, by placing the iron-wire, previously weighed, in a glass, or very compact earthen tube, instead of the gun-barrel, the weight which the iron will have acquired, added to the weight of the volume of gas produced, will be found exactly to make up the weight of the water decomposed; and they will be to one another in the proportion of eight to one.

(§ 48.) It is needless to dwell upon the

more obvious properties of the well-known fluid water, which is so abundantly diffused over the face of the earth. The purest state in which it is offered to us by nature, is as it descends from the clouds in the form of rain. It is colourless, inodorous, and insipid; and these negative characters confer upon it its greatest value. To enumerate its uses would be to transcribe a long chapter indeed from the book of nature, and is quite incompatible with our present limits. We must confine ourselves to marking a few of its characteristics in the three states in which it is presented to our observation, viz. as a liquid, a solid, or *ice*, and an *aëriform* fluid, or *steam*.

(§ 49.) It has been an object of the greatest importance to ascertain with precision the weight of a given volume of pure water, as it is the standard with which all other liquids and solids are compared; as the weights of *aëriform* fluids are with atmospheric air. Moreover, a recent act of parliament declares that the standard measure of capacity shall be the gallon, containing 10 lbs. avoirdupoise weight (7000 grains = 1 lb.) of distilled water, weighed in the air at the temperature of 62° of Fahrenheit's thermometer; the barometer being at 30 inches. The capacity of this gallon is 277.274 cubic inches.

From the most careful experiments, it appears that a cubic inch of water, at the temperature of 60°, weighs 252.52 grains, and consists of 28.06 grains of hydrogen, and 224.46 grains of oxygen. The volume of the former gas is 1325 cubic inches, and of the latter 662, making together 1987 cubic inches; so that the condensation is very nearly 2000 volumes into one.

(§ 50.) The effect of temperature upon liquid water is distinguished by a peculiarity of a very striking nature, and exhibits a departure from a general law of nature, for a purpose so obviously wise and beneficent, as to afford one of the strongest and most impressive of those endless proofs of design and omniscience in the frame of creation, which it is the most exalted pleasure of the chemist, no less than of the naturalist, to trace and admire.

All liquids, except water, contract in volume as they cool down to their points of congelation; but the point of greatest density in water is about 40°; its freezing point being 32°. As its temperature deviates from this point, either upwards

or downwards, its density diminishes; or, in other words, its volume increases. This peculiar law is of much greater consequence in the economy of nature, than might at first be supposed. The water which covers so large a portion of the surface of the globe, is one of the most efficient means of equalizing its temperature, and rendering those parts habitable, which would otherwise be bound up in perpetual frost, or scorched with intolerable heat. The cold air which rushes from the polar regions progressively abstracts the heat, from the great natural basins of water or lakes, till the whole mass is reduced to 40° ; but at this point, by a wise providence, the refrigerating influence of the atmosphere becomes nearly null: for the superficial stratum, by further cooling, becomes specifically lighter; and instead of sinking to the bottom as before, and displacing the warmer water, it now remains at the surface, becomes converted into a cake of ice, and preserves the subjacent water from the further influence of the cold. If, like mercury, it continued to increase in density to its freezing point, the cold air would continue to rob the mass of water of its heat, till the whole sunk to 32° , when it would immediately set into a solid stratum of ice, and every living animal in it would perish: and in these latitudes, a deep lake so frozen would never again be liquefied.

(§ 51.) Water, at the moment that it assumes the solid form of ice, experiences a sudden expansion of still greater amount than the preceding. Its bulk is enlarged in the proportion of nine to eight; and in the act of freezing, if confined, it is capable of bursting the strongest vessels. The common experience in hard frosts of the cracking of water-pipes or of vessels in which water is suffered to freeze without room for this expansion, bears testimony to the fact. In consequence of its being specifically lighter, ice always swims upon the surface of water.

(§ 52.) A cubic inch of water at 40° is expanded by heat into 1694 inches, or nearly a cubic foot of steam, at the temperature of 212° ; at which point its elasticity is equal to the mean elasticity of the atmosphere, or 30 inches of mercury: and when given off in this state it occasions the phenomena of boiling. The principal properties of steam may be exhibited in the following way. Procure a glass tube, *fig. 7*, about $\frac{3}{4}$ inch bore and 7 or

8 inches in length, closed at one end, and a little enlarged at the same extremity, by blowing into it when softened by heat. Wrap a piece of thin wash-leather round one end of a rod of wood 10 inches long, till it just fits into the tube and forms a piston, which will move freely in it. Pass the glass tube through a perforated cork, so as to form

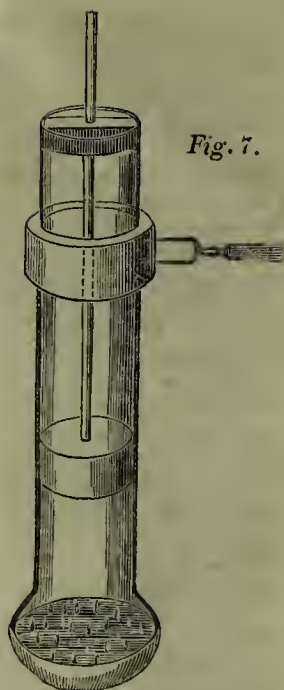


Fig. 7.

an exterior collar at its upper end. Stick a fork into this to form a handle, by which it may be held over the flame of a lamp. Put a little water into the bottom and heat it. When it boils briskly the air will be expelled by the steam, and the piston is then to be introduced a little way. Plunge the tube into cold water, and the steam will be instantly condensed, and the piston will be driven down by the pressure of the atmosphere upon the vacuum thus formed under it. Cause the water again to boil, by holding it over the flame, and the elastic force of the steam will drive the piston upwards; which motions may be alternately produced by repeatedly heating and cooling the water in the bulb of the tube. It is the production and sudden annihilation of this elastic force which is the source of the prodigious power of the steam-engine.

Steam is perfectly transparent and invisible, as may be observed when the water boils and the tube is filled with it, or as it at first issues from the spout of a tea kettle. It is only when it is beginning to be condensed that it puts on that cloudy appearance which many people suppose to be essential to it.

(§ 53.) But steam is not only formed from water at its boiling point, but rises slowly and quietly from it at all temperatures, even below the freezing point.

It is always found mixed with the permanent gases of the atmosphere, even in the driest weather; as may be seen by the dew which is deposited upon cold bodies, such as a glass of water fresh drawn from a well in summer. Its elasticity at the freezing point is equal to 0.200 inch of mercury, and its force increases in a geometrical progression for equal increments of temperature.

Oxygenized Water.—17.

(2 O. 16 + 1 H. 1).

(§ 54.) It was long supposed that there was only one compound of oxygen and hydrogen; but another has lately been discovered, in which hydrogen is united with a double proportion of oxygen, the numbers being, hydrogen 1, oxygen 16, or equal volumes of the two.

The only process at present known, by which it can be produced, is difficult, complicated, and expensive: so much so, that it is doubtful whether it has been ever tried in this country. We shall therefore pass it over, at present, and merely mention, that this oxygenized water is possessed of new and very remarkable properties. It is necessary to keep it surrounded by ice; for at a temperature of 58° it is decomposed, and oxygen gas is given off in abundance. It is liquid and colourless, like water; but produces upon the tongue a metallic taste. It attacks the skin with rapidity, bleaches it, and occasions a smarting sensation. By throwing some metals into it, in a state of fine division, such as silver or platinum, explosions are produced without effecting any change upon them, in a way which is not easily understood.

(§ 55.) In the systematic language of Chemistry (which has greatly conduced, by its simplicity and its ready adaptation to new facts, to the advancement of the science; and the principles of which we shall endeavour to explain as we proceed), the combinations of oxygen with other bodies, which are not acid, are termed *oxides*: and if more than one such compound with the same body should be known, they are distinguished as first, second, or third oxide, by the appellations, derived from the Greek numerals, of *protoxide*, *deutoxide*, *tritoxide*, or the furthest degree of oxidation is denoted by the term *peroxide*. In this language, therefore, water is the *protoxide* of hydrogen; and the compound to which we have just referred is the *deutoxide*, or *peroxide* of hydrogen.

ON NITROGEN.—14.

(§ 56.) THE next of the four gaseous simple substances, which we shall describe, is Nitrogen (or, as it has sometimes been named, Azote*). Like hydrogen, it belongs to the electro-positive class, being attracted by the negative pole of the Voltaic pile.

It constitutes four-fifths of the atmosphere of our globe, and may most readily be obtained for examination by removing the oxygen with which it is mixed, by the action of some superior affinity. The residue of atmospheric air, in which phosphorus has been suffered to burn out, after standing a little while over water, consists of tolerably pure nitrogen; or the oxygen may be absorbed by allowing the air to stand in a receiver over a mixture of equal weights of iron filings, and sulphur made into a paste with water.

(§ 57.) Nitrogen gas is distinguished by negative characters, rather than by any active properties.

It is colourless, inodorous, and tasteless; it is not absorbed by water, or only in very minute portions; no animal can live in it; it is not inflammable, and it instantly extinguishes all burning bodies introduced into it.

It is a little lighter than atmospheric air, 100 cubic inches weighing 29.7 grains.

NITROGEN WITH OXYGEN.

(§ 58.) NITROGEN may be mixed with oxygen in any proportion; but four parts by volume of the former, and one of the latter, form a mixture resembling atmospheric air in all its properties. The atmosphere also contains a variable proportion of vapour of water as we have already stated (§ 53), and very minute portions of other matters which will be mentioned hereafter: its essential characters are, however, derived from these two ingredients.

The invariable uniformity of this mixture is one of the most surprising facts with which chemistry has made us acquainted. Air has been examined in the most accurate manner, which has been collected, by means of a balloon, from a height of nearly 22,000 feet; and at the level of the sea; from the heart of the most crowded districts of the most populous towns; and from the summit of Mont Blanc; from within the polar

* From a Greek expression, signifying "privation of life."

circle; and from the equator; and no difference has been discovered in its proportions. The active properties of atmospheric air are all referable to the oxygen which it contains, and are those of that body diluted. Without oxygen no animal could live—in pure oxygen they would live, if the expression may be allowed, too rapidly, as a candle would burn with too great intensity. All the vital functions would be increased to a morbid excess. Many experiments have been tried upon the subject, but no gas, or mixture of gases, has ever been discovered which can support life in the same uniform manner as the mixture which has been so admirably adapted to the purpose, and so wonderfully preserved from change. All the common processes of combustion are the result of the affinity of the oxygen of the atmosphere for the bodies which burn in it, and in all it is consumed; but notwithstanding the enormous consumption, from this and other causes, it is perpetually renewed, and its proportion maintained, by an adaptation of means to the end so nicely adjusted, as to form one of the greatest wonders where all is admirable.

(§ 59.) There are no known means of making nitrogen and oxygen combine directly in a more intimate manner; and this is probably one provision for the permanence and salubrity of the air we breathe; as such compounds otherwise obtained are all noxious, and most of them corrosive and poisonous. Indications of such a direct union have, indeed, been obtained by passing strong electric sparks through portions of common air, but it was effected with great labour and perseverance.

Five distinct compounds may, however, be produced by other means; and they admirably illustrate the change of properties conferred by composition in different, but multiple proportions. The first two belong to the class of oxides, not having any acid properties; and they may be called the protoxide and the deutoxide of nitrogen. The three last are acids.

(§ 60.) Now when a substance forms more than one acid combination with oxygen in different proportions, the chemical nomenclature distinguishes them as follows:—

The highest degree of oxygenation is marked by its name terminating in *ic*, as the *nitric acid*; that of the next degree is made to terminate in *ous*, as the

nitrous acid; and should there be an acid of a degree still lower, the Greek preposition *hypo* (under) is prefixed, to denote an under proportion of oxygen, as the *hyponitrous acid*.

Protoxide of Nitrogen.—22 (1 N. 14 + 1 O. 8).

(§ 61.) THE protoxide of nitrogen (or as it is sometimes called *nitrous oxide*) is best obtained by fusing a salt called Nitrate of Ammonia in a retort over an argand lamp. This salt is not always to be obtained, but is very easily formed by dissolving Carbonate of Ammonia (of which the common smelling salts are made) in nitric acid (*aqua fortis*) diluted with five or six parts of water. The solution is to be evaporated, till a drop of it, taken out upon a glass rod, concretes on cooling.

When the salt is liquefied, it should be cautiously kept simmering by a gentle heat; the gas is given off, and may be collected over water; but as it is absorbed by this fluid in a considerable proportion, the tube through which it passes into the jar should be conducted to its top, *fig. 8*, that it may not have to pass the whole column.

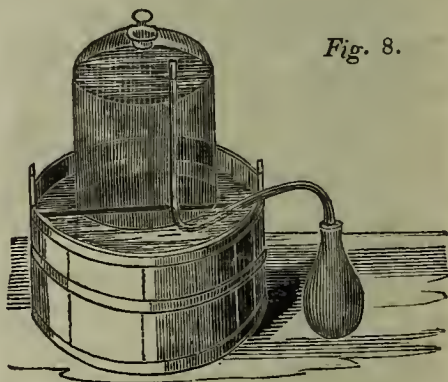


Fig. 8.

(§ 62.) The protoxide of nitrogen is a colourless, elastic fluid, considerably heavier than common air, 100 cubic inches weighing 46.5 grains. It has a sweetish taste, and faint agreeable smell. Water dissolves about its own bulk of this gas. Animals, when wholly confined in it, die very speedily; it may, however, be breathed for a short time with impunity; and it has been found to produce a most extraordinary excitement in the human frame. The experiment may be tried, by filling a clean bladder with it, and inhaling it repeatedly through a pipe attached to a stop-cock. Care

should be taken that the gas is very pure. The sensations which it produces have been variously described by different people, but all have agreed that they are very agreeable, and much resemble the exhilaration produced by spirituous liquors. It has mostly occasioned an irresistible propensity to laughter and muscular exertion, not followed by that depression and sense of lassitude which generally succeed excitement from fermented liquors.

This gas does not change the colour of blue vegetable infusions, and, therefore, is not acid.

Many substances, when introduced into it in a state of inflammation, burn with great splendour, from their superior affinity for the oxygen, with which they combine, setting nitrogen free. The glowing wick of an extinguished taper is immediately kindled by it into flame.

Iron-wire, and red-hot charcoal, burn in it, with nearly the same splendour as in oxygen gas, but for a shorter time.

Phosphorus introduced into it, in a state of active inflammation, burns with great violence, almost approaching to explosion.

When mixed with hydrogen, it will detonate either by the application of flame, or of an electric spark.

(§ 63.) Two volumes of the protoxide require two volumes of hydrogen for their complete decomposition, and the residue is two volumes of nitrogen. The experiment may be tried in the apparatus previously described for the detonation of mixtures of oxygen and hydrogen, *fig. 6*.

Now, as two volumes of hydrogen are equivalent to the saturation of one volume of oxygen, we infer that the protoxide of nitrogen is composed of two volumes of nitrogen and one of oxygen, condensed into two volumes; and the specific gravity of the gas confirms this influence, for the weight of

100 cubic inches of nitrogen is	29.7 gas (§ 57)
and of 50 oxygen	16.8 (§ 37)

making the weight of 100	
cubic inches of protoxide	46.5

as before stated from experiment.

(§ 64.) The equivalent number of nitrogen is also deduced from the same data for

16.8 : 29.7 :: 8 : 14,
that is to say, the number for oxygen being denoted by 8, that of nitrogen must be 14; these two numbers being in

the same proportion (allowing for the unavoidable inaccuracies of delicate experiments) as 16.8 to 29.7, the combining weights in the above experiment.

This is an example of the mode of reasoning, by which the composition of a body may be deduced from the results of analysis; which, as the protoxide of nitrogen cannot be formed by the direct union of its elements, is the only means of ascertaining it in the instance before us. The method is unobjectionable, but the proof not so satisfactory as when we are able to confirm it by synthesis. When the two methods concur, the conclusion, which rests upon them, has all the certainty of a mathematical demonstration.

Deutoxide of Nitrogen.—30.
(1 N. 14 + 2 O. 16.)

(§ 65.) THE deutoxide of nitrogen (or, as it is sometimes denominated, nitric oxide) may be obtained from the action of nitric acid (aqua fortis) upon copper. The metal may be put into a retort, and the acid poured upon it, when a brisk effervescence will take place, and the gas may be collected in a jar in the water-bath.

(§ 66.) It is a permanent elastic fluid, very sparingly soluble in water, and does not, when pure, act upon blue vegetable colours. It is wholly irrespirable. The flame of most bodies, as of a taper or sulphur, is instantly extinguished, by being immersed in it; but it parts with its oxygen to charcoal and phosphorus, if introduced in a state of vivid inflammation, and they burn in it with increased energy. It does not explode, when mixed with hydrogen in any proportion; but it colours its flame green, if burnt with it in the common air.

It is but little heavier than atmospheric air, 100 cubic inches weighing 31.7 grains. When mixed with oxygen gas, deep red fumes are generated; and if the experiment be made over water, a great absorption will ensue; and when the gases are perfectly pure, and mixed in the proper proportions, they entirely disappear. The same appearance takes place with atmospheric air, and the diminution upon mixture is proportionate to the quantity of oxygen which it contains. From this property of condensing oxygen, and no other gas, it has been much used in *eudiometry*, or for measuring the purity of atmospheric air, which was formerly supposed to depend upon a varying proportion of that gas.

In this process an acid is formed, as

may be proved by the following experiment. Paste a slip of paper, stained with litmus, within a glass jar; and into the jar, filled with, and inverted over water, admit as much Deutoxide of Nitrogen, well washed by agitation with water, as will displace the water below the level of the paper. The blue colour will remain unchanged; but on admitting common air, or oxygen, it will be immediately reddened.

It may be decomposed by suffering it to stand over iron filings, which abstract a portion of its oxygen, and convert it into protoxide of nitrogen.

(§ 67.) Its composition has been accurately ascertained by burning charcoal in it, which combines with the whole of its oxygen, amounting to half its volume, and leaves nitrogen to the amount of the other half. Hence we infer that it is composed of equal volumes of the two gases uncondensed: and that the volume of oxygen is exactly the double of that in the preceding compound. This result agrees exactly with its weight, for

	Grains.
50 cubic inches of oxygen	
weigh	16.5 (§ 37.)
50 cubic inches of nitrogen	
weigh	14.9 (§ 57.)
making together	31.7

the weight of 100 cubic inches of the deutoxide as before stated from experiment.

Its composition, therefore, upon the scale of equivalents is,

1 equivalent of nitrogen . . .	14
2 ditto of oxygen	16
	30

Hypnitrous Acid.—38.

(1 N. 14 + 3 O. 24)

(§ 68.) The next combination, in order, of nitrogen with oxygen, the hypnitrous acid, is rather hypothetical (conjectural), inasmuch as it never has been exhibited in a detached form.

For its production, a mixture of deutoxide of nitrogen and oxygen must be made over mercury, instead of water, upon the surface of which a little solution of potash must float. The proportions must be 4 volumes of the former, and 1 of the latter. They combine together under these circumstances, and form an acid which immediately unites with the potash, but which cannot afterwards be separated from it without undergoing

decomposition. It will not be necessary to say more upon this compound, and we only notice it as forming a link between the last and the next compound. We have seen that 4 volumes of the deutoxide are composed of

2 volumes of nitrogen

2 volumes of oxygen,

and the additional volume makes 3 volumes of oxygen to 2 of nitrogen in the composition of hypnitrous acid, or in numbers,

1 proportion of nitrogen . . .	14
3 ditto of oxygen	24
	38

Nitrous Acid.—46. (1 N. 14 + 4 O. 32.)

(§ 69.) The next compound is the nitrous acid, which may also be produced by adding oxygen to the deutoxide of nitrogen. The experiment will not succeed over water or mercury, but may be conducted in a glass retort, fitted with a stop-cock, from which the air has been extracted by an exhausting syringe. In this way a mixture may be made of 2 measures of the deutoxide, and 1 measure of oxygen, which will be condensed into half their volume, and form a deep orange-coloured gas: 2 volumes of the deutoxide are composed, as we have seen,

1 volume of nitrogen, and

1 volume of oxygen,

and 1 volume of oxygen now added, form 2 volumes of oxygen to 1 of nitrogen in the composition of nitrous acid, or in numbers,

1 equivalent of nitrogen . . .	14
4 ditto of oxygen	32

equivalent of nitrous acid 46

(§ 70.) A taper will burn in this gas, and phosphorus most vividly. Charcoal also burns in it with a dull red light.

Water dissolves it, and acquires a green tint, which changes to blue, and finally to yellow, as more of the gas is absorbed. The solution is sour, reddens litmus paper, and stains animal substances yellow. It has been called liquid nitrous acid; but with regard to this solution, there is some ambiguity to which we shall hereafter again refer.

No practically useful application has been made of any of these compounds.

Nitric Acid.—54. (1 N. 14 + 5 O. 40.)

(§ 71.) We have already mentioned that by laboriously passing electric sparks, from a powerful machine, through a

mixture of oxygen and nitrogen, some indications are obtained of an union between the two gases: the product is a small quantity of nitric acid.

This acid may readily be produced by passing the deutoxide of nitrogen *very slowly* into oxygen gas, standing over water. By this operation, four volumes of the former combine with three of the latter; and the compound, therefore, must consist of 2 volumes nitrogen, and 5 volumes oxygen, or by weight of

1 equivalent of nitrogen	14
5 ditto of oxygen	40

—
making the equivalent of nitric acid 54

The acid as it is formed is absorbed by the water, and it is very doubtful whether it can be exhibited in an insulated state.

(§ 72.) The liquid nitric acid is of very great importance in the arts, and is used in large quantities. It is procured, for commerce, by distilling nitre with strong sulphuric acid: the product is an intensely acid liquid, which, when pure, is colourless, and when most concentrated has a specific gravity of 1.5; that is to say, it is by half heavier than water. In this state it contains 25 per cent. of water; which is the least quantity with which it is known to exist, and is therefore a definite compound of

1 equivalent nitric acid	54
2 ditto of water (9×2)	18

—
72

which are in the same proportion to each other as 75:25. And we have before shewn (§ 44), in speaking of the union of oxygen with hydrogen, that the equivalent of water is 9.

In this state it is called *hydro-nitric acid* (from a Greek word, signifying water) to denote this combination. In entering into other compounds, it abandons the water and combines in the dry, or, as it is termed, the *anhydrous* state.

It may be *mixed* with water in any proportions beyond the 25 per cent.

(§ 73.) The nitric acid is a highly corrosive fluid, and acts as a powerful caustery when applied to the skin, which it stains of a permanent yellow. It is decomposed, with great violence, by most substances which have an affinity for oxygen; which element enters so largely into its composition. If it be brought into contact with hydrogen, at a high temperature, a violent detonation will be the consequence; but the experiment is dangerous, and should not be made

without great caution. When poured upon warm, dry charcoal in powder, combustion ensues, with the emission of copious fumes of deutoxide of nitrogen. Spirits of turpentine may be inflamed by suddenly pouring nitric acid upon it: the acid should be poured out of a phial attached to a long stick, or there would be danger to the eyes of the operator.

(§ 74.) In reviewing these various compounds of oxygen and nitrogen, the mind cannot but be impressed with the wonderful nature of that species of attraction which, by such apparently simple means, as mere variation of proportions and approximation of particles of two bodies, can confer such essentially different properties upon matter! In the atmosphere by which we are surrounded, we are presented with an active principle, essential to the existence of life, but injurious in its pure state, diluted by measure and weight, with an inert fluid to the exact proportion which is most beneficial to animal existence. It is perpetually consumed and perpetually renewed; but never exceeds or falls short of its determined quantity. This bland, tasteless, inodorous, invisible mixture, in which we are perpetually immersed, and upon the maintenance of which our existence depends, by the mere approximation of its particles, in a manner to us mysterious, is capable of being converted into a poisonous, corrosive, suffocating red vapour, which would instantly destroy all organized matter. By approximating in other proportions, an intoxicating deleterious atmosphere would be produced; or compounds with other properties, but all destructive of life. Such affinities, it is clear, exist; but are happily restrained by the Great Legislator who framed the laws of nature.

NITROGEN WITH HYDROGEN.

Ammonia.—17. ($1 \text{ N. } 14 + 3 \text{ H. } 3$).

(§ 75.) We come now to examine the affinity between nitrogen and hydrogen. These two gases may be *mixed* in any proportions; but there are no means known of causing them to unite *directly* in a more intimate manner. Such a compound may, however, be obtained *indirectly*. There is a saline body, well known in the arts by the name of *sals-ammoniac*: if some of this salt be finely pounded, and mixed with an equal quantity of unslaked quick lime, in powder, and introduced into a tube or retort, upon the application of a gentle heat, it will give out an extremely pun-

gent smell, well known as arising from spirits of hartshorn. This proceeds from the evolution of a gas, which is rapidly absorbed by water, and therefore cannot be collected, as the gases we have hitherto treated of, over that liquid. It may, however, be obtained in jars filled with mercury, in a similar way to the water bath; and various forms of apparatus have been contrived to facilitate the operation in this and similar instances, and to economise the mercury, which is an expensive article. Its principal properties may, however, be exhibited by collecting it in a prepared bladder, made thin by scraping, and furnished with a stop-cock, which may be attached to the mouth of the retort containing the above mixture. It will become inflated as the gas is given off; and it may be preserved for a short time by closing the cock and detaching the glass. This elastic fluid is called ammonia.

(§ 76.) An animal plunged into it immediately dies, and the flame of burning bodies is extinguished by it. The flame of a taper becomes enlarged, with a kind of yellow halo before it goes out, shewing an inclination of the gas itself to burn; and if a small jet of it be introduced into a jar of oxygen, it may be inflamed—the product of the combustion being water and nitrogen.

It is very much lighter than common air, 100 cubic inches only weighing 18.05 grains.

It changes the blue colour of vegetables to green, and yellows to brown; but not permanently, for as the gas escapes the original colour returns.

(§ 77.) Ammonia may be resolved into nitrogen and hydrogen gases, by passing it through a red hot tube; and more rapidly, if the heated surface over which it is driven be increased by iron-wire coiled up in the tube. The experiment may be made in the apparatus before described, (§ 47,) by filling a bladder with the gas, expelling it through the heated tube by pressure, and receiving the nitrogen and hydrogen in a jar upon the water-bath. A mixture of ammonia and oxygen may be inflamed by the electric spark, just as a mixture of oxygen and hydrogen. The mere passing electric sparks through it also effects its decomposition. By this process its bulk is gradually enlarged, and when two or three hundred discharges have passed through a cubic inch of it, it will be found to have doubled its volume.

Two volumes of ammonia produce, by their decomposition, 4 volumes; con-

sisting of 3 volumes of hydrogen, and 1 volume of nitrogen.

Now, 150 cubic inches	
of hydrogen weigh	. 3.15 grs. (§ 41)
and 50 ditto nitrogen	. 14.9 grs. (§ 57)

Together 18.05

which, as 2 volumes are condensed into 1, will be the weight of 100 cubic inches of ammonia, and agrees with the direct experiment. Its constitution, therefore, by weight is—

One equivalent of nitrogen	. 14
Three ditto hydrogen	. 3

and its equivalent . . . 17

(§ 78.) The solution of ammonia in water is commonly known by the name of liquid ammonia; but incorrectly, as the pure gas is capable of assuming the liquid form under high pressure, equal to that of $6\frac{1}{2}$ atmospheres, or 195 inches of mercury.

The aqueous solution of ammonia, which is an article of great importance and extensive use, may be prepared by passing the gas, as it is formed, directly into water, which, at the temperature of 50° , will take up 670 times its volume; its bulk is thereby increased, and its specific gravity diminished: that of a saturated solution is .875, water being 1000.

The solution may be more conveniently prepared by the following process:—On 9 ounces of well-burnt lime pour half a pint of pure water; and when it has remained in a well-closed vessel about an hour, add 12 ounces of *sal ammoniac* in powder, and three pints and a half of boiling water. When the mixture has cooled, pour off the clear portion, and distil from a retort 20 fluid ounces. The specific gravity of this solution is .954.

It possesses the peculiar pungent smell, taste, and alkaline properties of the gas itself, and has the same action upon vegetable colours.

(§ 79.) We have thus arrived at the knowledge of two principal compounds of nitrogen, of the directly opposite qualities which characterize two great classes of bodies called *acids* and *alkalies*. The first, with 5 proportions of oxygen, constituting the nitric acid, intensely sour, corrosive, and turning the blue colour of vegetables red; the second, with 3 proportions of hydrogen, producing the volatile alkali or ammonia, hot, bitter, caustic, converting vegetable blues to green, and yellows to brown.

It will, we conceive, greatly facilitate

the comprehension of the subjects of affinity and definite proportion, if we stop to illustrate them, by considering the further combination of these two bodies together; although it does not enter into our general plan to examine the properties of bodies of this class, till we have completed the list of simple substances, and their binary compounds.

(§ 80.) By carefully dropping a solution of ammonia into diluted nitric acid, they will neutralize each other; and the exact point of saturation may be ascertained, by dipping into the solution, from time to time, small slips of paper stained with litmus and turmeric: when these colours are no longer affected, the neutralization is complete. The solution will now be neither acid, corrosive, alkaline, nor caustic; but its taste will be saline and bitter. If the liquor be carefully evaporated at a temperature not exceeding 100° , it will shoot, on cooling, into prismatic crystals. The salt so produced is called nitrate of ammonia, and is a definite compound of nitric acid, ammonia, and water. Its proportions have been very carefully ascertained to be in 100 parts,

acid	. 67.63
alkali	. 21.14
water	. 11.23

100

which are in proportion to each other as

1 equivalent nitric acid	. 54 (§ 71.)
1 ditto ammonia	. 17 (§ 77.)
1 ditto water	. 9 (§ 44.)

the numbers for which were formerly obtained from the direct combination of the elements of each.

(§ 81.) Water thus combined with a salt is called its *water of crystallization*: it is essential to its existence in the crystalline state, but may be generally expelled by heat, leaving the *anhydrous* salt in an amorphous (or shapeless) state, but with all its properties unchanged.

This it is difficult to effect in the present instance, as the salt is very easily decomposed by heat, and at a temperature of 600 explodes, being wholly resolved into its elements.

(§ 82.) The results of its decomposition at a lower temperature we have already shewn (§ 61), in describing the formation of the protoxide of nitrogen; and this process may now be understood.

Nitrate of ammonia, which is melted at a gentle heat, is composed of

1 equivalent nitric acid, 54	{ 1 equ. nitrogen, 14
	5 do. oxygen, 40

1 equivalent ammonia, 17 { 1 equ. nitrogen, 14
3 do. hydrogen, 3
or, in other words, the salt is composed of

2 equivalents nitrogen	. . . 28
3 do. hydrogen	. . . 3
5 do. oxygen	. . . 40

In this decomposition the 3 proportions of hydrogen take 3 of oxygen, and form water; and the remaining 2 proportions of oxygen combine with the 2 of nitrogen, and produce the protoxide of nitrogen: and these are the only products.

It is almost impossible for the least contemplative mind not to be struck with admiration at the harmonious simplicity of the laws upon which these transmutations depend: and the feeling of satisfaction which their development produces is part of that pure delight which, independently of more substantial advantages, rewards the diligent student of the works of nature.

ON CHLORINE*.—36.

(§ 83.) CHLORINE, the last of the four æriform elements which we have enumerated, belongs, with oxygen, to the electro-negative class; being evolved from all its compositions, except with oxygen, at the positive pole of the Voltaic pile. It may be obtained as follows:—Mix three parts of sea-salt finely pounded with one of peroxide of manganese—a substance well known in several of the arts by the name of black manganese; pour upon them in a retort two parts of sulphuric acid diluted with an equal weight of water: by the action of a gentle heat the gas will be given off. It may also be obtained by the action of muriatic acid upon the same oxide.

Cold water dissolves about twice its volume of chlorine; and mercury rapidly combines with it. It is best collected over warm water; and the waste from absorption may be diminished by leading the pipe, by which it is conducted, to the top of the jar; as was before recommended for the protoxide of nitrogen (§ 61.) It may be preserved in bottles with glass stoppers well greased, taking care that the water is wholly expelled from them.

(§ 84.) It possesses a yellowish green colour, an astringent taste, and a most suffocating smell; all of which

* From a Greek word, signifying "green," from its colour.

qualities are communicated to its aqueous solution. If received into the lungs, its action is extremely painful and injurious.

It is considerably heavier than common air: 100 cubic inches weigh 76.3 grains.

When a burning taper is introduced into it, it is quickly consumed with a dull red flame, which throws off a dense black smoke: phosphorus spontaneously ignites in it, and burns with a pale white flame; and several of the metals, in a finely-divided state, or in thin leaves, inflame: and in this way tin, copper, and zinc, exhibit a beautiful appearance.

Chlorine, mixed with the vapour of water, as it is usually obtained, assumes the liquid form at a temperature of 40° ; and when surrounded with snow or pounded ice, concretes into a solid of a yellowish colour; which is deposited upon the sides of the receiver, like the effects of frost upon the surface of windows. If the gas be artificially dried by passing it over substances which abstract vapour, as a salt known by the name of muriate of lime, the most intense artificial cold produces no effect upon it. Strong compression, equal to four atmospheres, will, however, reduce it to the liquid form. It has no acid properties: it is not sour, and it does not change the blue colour of vegetables to red; but it destroys all animal and vegetable colours, and is a most important agent in the art of bleaching. This, however, it can only effect when water is present. If a piece of dry litmus paper be introduced into a jar of dry chlorine, it will suffer no change; but if previously wetted, the colour will speedily disappear. The colours of printed calico may readily be discharged by the same means.

CHLORINE AND HYDROGEN.

Muriatic Acid.—37. (1 Ch. 36 + 1 H. 1.)

(§ 85.) CHLORINE and hydrogen may be mixed together; and if carefully excluded from the light of day, will remain without change. If the mixture be made with equal volumes of the two, and exposed to light, they will gradually combine; the chlorine will lose its peculiar colour and smell, and a powerfully acid gas will result, without any change of volume. If the mixture be made in a stout phial, with a well-fitted stopper, secured by wrapping a cloth round the neck, and exposed to the direct rays of the sun, the combination will take place

suddenly and with detonation. When the stopper is afterwards withdrawn under mercury, it will be found that no condensation has taken place; but if under water, it will instantly rush in and fill the phial—as the new compound is rapidly absorbed by that liquid. The mixture may also be exploded by flame, or the electric spark.

To this compound the name of muriatic acid has been given, and it is sometimes called hydrochloric acid. As the elements combine without condensation, its specific gravity must be the mean between those of its two ingredients.

50 cubic inches of chlorine	weigh	. . .	38.10	(§ 84.)
50 ditto of hydrogen			1.05	(§ 41.)

100 cubic inches of muriatic acid must therefore	weigh	. . .	39.15
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which agrees very nearly with direct experiment.

(§ 86.) Muriatic acid gas is best obtained by the action of strong sulphuric acid upon an equal weight of sea salt: it is given off in great purity, but must be collected over mercury.

The properties of such gases as are rapidly absorbed by water, may be examined without a regular mercurial apparatus, by means of a glass tube from half to three-quarters of an inch diameter, and from four to ten inches in length. It is closed above, but open at the lower extremity, and turned up (*fig. 9*). It may be filled with mercury, and is then to be supported with a saucer beneath it. The soluble gas may be produced in a small tube, or retort, drawn out, and fixed in such a way that the end may be introduced at the mouth so far as to allow the bubbles to pass into the tube, and the mercury to flow out into the saucer. When the metal

Fig. 9.



has descended nearly to the bend, the operation should be stopped. Small portions of the gas so collected, may afterwards be examined, by placing the finger upon the aperture in contact with the mercury, so as to exclude all air. By inclining the tube, a bubble of the gas may be made to pass round the bend towards the finger; and upon replacing the tube in the perpendicular position, the larger quantity will still be in the upright part, and a

small quantity confined between the mercury and the finger, and quite unconnected with the former. This quantity may thus be conveniently experimented upon.

(§ 87.) Muriatic acid gas is colourless, of a very pungent smell, and intensely acid taste.

Its attraction for water is so great, that when a little of it escapes into the air, a white cloud is instantly formed by its combining with the atmospheric steam.

It extinguishes flame and is combustible.

It instantly reddens blue vegetable colours.

It has been reduced to a liquid state by a pressure amounting to that of 40 atmospheres.

Water, at the temperature of 40° , will absorb of it about 480 times its volume, and thereby increases its bulk. The solution is commonly known by the name of muriatic acid, and is largely employed for chemical purposes. It may be prepared by passing the gas, produced as above, immediately into water; or by adding a sufficiency of water to the sulphuric acid in the first instance, and then distilling. The solution, when pure, is perfectly colourless, and it possesses all the acid properties and smell of the gas. Its specific gravity is greater than that of water, and when it amounts to 1.920 (water being considered 1.00) 100 parts contain 28.3 of real acid.

When muriatic acid is brought into contact with some oxides, they part with a portion of their oxygen, which forms water with its hydrogen, and chlorine is evolved: it is thus that the process previously described (§ 83) for obtaining chlorine with oxide of manganese may be explained.

The muriatic acid is the only known compound of chlorine with hydrogen.

CHLORINE AND OXYGEN.

Protoxide of Chlorine.—44.

(1 C. 36 + 1 O. 8.)

(§ 88.) CHLORINE and oxygen have but a feeble affinity for each other; but four distinct compounds of the two elements may be obtained by indirect means. They are never found in nature, and are subjects of instruction and curiosity rather than of use in the arts.

There is a salt to which we have before referred (§ 36), and the formation of which will be hereafter described, known by the name of *chlorate of potash*:

when this salt is heated in a retort, with very weak muriatic acid, a gas may be collected over mercury: but as it is very apt to explode, the application of a naked flame to the retort should be avoided, and the heat is best applied by the medium of water. It differs very materially from chlorine.

(§ 89.) Its colour is much deeper, and is of a brighter yellow tint: its smell is intermediate between that of burnt sugar and chlorine.

It explodes by the application of a very gentle heat, not exceeding that of the hand, and is decomposed. Five volumes become expanded to 6, consisting of a mixture of chlorine and oxygen, in the proportions of 4 of the former to 2 of the latter; the oxygen in the compound being condensed into half its bulk. These proportions prove that it is a compound by weight of

1 equivalent of chlorine	. . 36
1 ditto oxygen	. . 8

Its number therefore is . 44

It may be called the protoxide of chlorine.

Water dissolves eight or ten times its bulk of this gas, and takes an orange tint, but it does not act upon mercury.

It discharges all vegetable colours. Phosphorus upon being plunged into it takes fire, and causes it to explode.

It may be mixed with hydrogen, and exploded by the electric spark, and muriatic acid and water are the products.

Peroxide of Chlorine.—68.

(1 C. 36 + 4 O. 32.)

(§ 90.) ANOTHER combination of chlorine and oxygen may be obtained by operating upon *chlorate of potash* with sulphuric acid: 50 or 60 grains of the salt in powder may be mixed with strong sulphuric acid into a paste. The mixture will assume a bright orange colour. It may be placed in a small retort, or bent tube, which should be immersed in water, and gently heated, taking care to keep it under 212° , or the boiling point. A gas will be given off, which may be received over mercury, on which it has no action at common temperature.

(§ 91.) Its colour is also yellow, but brighter than that of the protoxide, and it is still more rapidly absorbed by water. The solution is deep yellow, and its taste not sour, but strongly astringent and disagreeable: it is decomposed by the action of light. The smell of this gas is peculiar and aromatic, and quite different

from that of chlorine. It explodes with great violence if heated to a temperature above 114° , and its volume is thereby increased by one-half. The products are chlorine and oxygen, in the proportions of 1 volume of chlorine to 2 of oxygen. It is, therefore, composed of

1 equivalent of chlorine . . .	36
4 ditto oxygen . . .	32

and its number is 68

It may be called the *peroxide* of chlorine. Phosphorus spontaneously ignites in it, and causes it to explode.

Chloric Acid.—76. (1 C. 36 + 5 O. 40.)

(§ 92.) THE combination of chlorine with a further proportion of oxygen constitutes an acid, which may be obtained by decomposing a salt, which will be hereafter described, called *chlorate of barytes*, by elective affinity with dilute sulphuric acid. Great care must be taken not to use an excess of sulphuric acid; which may be dropped into a solution of the chlorate in water, as long as any white precipitate appears. The clear liquor which remains, after the process is complete, should be cleansed from the sediment; it consists of a solution of *chloric acid* in water. It may be concentrated by careful evaporation till it acquires an oily consistency.

(§ 93.) It is colourless; its taste acid and astringent; and its smell, when warmed, pungent. It reddens the colour of blue vegetables. The chloric and muriatic acids decompose each other, and, if mixed in proper proportions, they are each resolved into chlorine by the union of the oxygen and hydrogen, with which they are severally combined. Chloric acid is composed of

1 equivalent of chlorine . . .	36
5 ditto oxygen . . .	40

and its number is 76

Perchloric Acid.—100.

(1 C. 36 + 8 O. 64.)

(§ 94.) A COMPOUND of chlorine, with a further proportion of oxygen, has been discovered, but very little examined. It has been obtained in the state of an acid liquor, and has been called *perchloric acid*. It is supposed to be composed of

1 equivalent chlorine . . .	36
8 ditto oxygen . . .	64

making its number 100

CHLORINE AND NITROGEN.

Chloride of Nitrogen.—158.

(4 C. 144 + 1 N. 14.)

(§ 95.) CHLORINE and nitrogen have but a very slight affinity for each other; but they may be obtained in union by passing chlorine through a solution of nitrate of ammonia at a temperature of about 90° . The chlorine is rapidly absorbed, and an oily film appears on the surface of the solution, which collects into yellowish drops, and sinks to the bottom of the vessel.

(§ 96.) This oily liquid is the most powerfully explosive compound known, and should not be experimented upon in quantities larger than a grain of mustard-seed; and even then it should be handled with extreme caution. Its specific gravity is 1.653, and it does not become solid at great degrees of artificial cold. At a temperature of about 200° it explodes; but the mere contact of some combustible substances, at ordinary temperatures, causes it to detonate. When a globule is thrown into olive oil, or turpentine, it explodes so violently as to shatter any glass vessel. The products of its decomposition are chlorine and nitrogen, and its composition has been inferred to be

1 equivalent nitrogen . . .	14
4 ditto chlorine . . .	144

making its number 158

(§ 97.) The name of chloride of nitrogen has been given to it: the chemical nomenclature conferring the appellation of *chloride* upon the combinations of chlorine with all bodies except oxygen, which have not acid properties: and as the analogous compounds of oxygen, when in more than one proportion, are distinguished by prefixing the Greek numerals, so the *chlorides* of different proportions are called *proto-chloride*, *deuto-chloride*, &c.

CHAPTER III.

On the Non-metallic Volatile Elements Bromine, Iodine, Sulphur, Phosphorus, and Selenium; and their Binary Compounds.

(§ 98.) THE principal object of all arrangement in science is to assist the memory in acquiring and recalling a knowledge of the phenomena of nature; and that arrangement is best which most completely fulfils this primary design. With this view we have already

divided the undecomposed substances into two classes, viz. the electro-negative and the electro-positive; but, for further convenience, these it is necessary again to subdivide; especially as the first class contains only four known and one hypothetical (conjectural) body, the existence of which requires to be established by further proof. We have, therefore, formed one groupe of those elements which always assume the gaseous form under the common circumstances of atmospheric temperature and pressure. Of these, two belong to the electro-negative and two to the electro-positive class, and their properties we have examined, and their combinations with each other.

We shall now proceed to describe five other simple substances: the first of which assumes, at common atmospheric temperature, the form of a liquid, and the others of solids; but all agree in being *volatile*, or in rising in vapour by the application of a moderate degree of heat: they are all, likewise, non-conductors of electricity, and bad conductors of heat. These have been called bromine, iodine, sulphur, phosphorus, and selenium. The first two are evolved from their respective compounds (except with oxygen and chlorine) at the positive pole of the voltaic pile; and with oxygen and chlorine, and that other substance whose existence, as we have said, has been rather inferred from analogy than proved, complete the number of the electro-negative elements.

*Bromine.**—75.

(§ 99.) ONE of the sources of the greatest discouragement to those who take but a hasty view of the science of chemistry, and a cursory glance at chemical systems, is the number of new substances and unusual names with which they are perplexed at the first outset of their inquiries. The forms of matter with which they are first presented, are not those with which they are most familiar; and as they do not at once see the practical application of the knowledge thus submitted to them, they are apt impatiently to give up the pursuit. The fact undoubtedly is, that a knowledge of these elementary substances, very few of which are presented to us in nature in their simple state, or even in their binary combinations, and a considerable number of which are the fruits of

modern research, constitutes the foundation of the science. The chemical compounds with which we are surrounded, and particularly the products of organization, are of a very intricate nature, and a knowledge of their constitution is most easily obtained by studying the properties of the elements, and ascending by the more simple combinations to the most complex. A large proportion, however, of the elementary substances are, as we have before mentioned, of very rare occurrence, even in a state of composition; and we would guard any one from the error of supposing that, because he may not have an opportunity of examining these scarce substances, a serious obstacle is thrown in the way of his advancement; for we again affirm, that such a sound practical knowledge of the science, as every one ought to acquire, may be attained by a well-directed study of the commoner elementary principles.

Bromine, as well as the next object of our investigation *Iodine*, have only been very lately discovered; and they belong to that class of substances, with whose use in the economy of nature we are at present totally unacquainted, and which have not yet been applied to any practical purpose: nevertheless, they are objects of the greatest interest to the chemist; and the study of their properties is particularly instructive, on account of the analogy which subsists between them and chlorine.

(§ 100.) Bromine has been obtained in very small quantities from sea-water and the ashes of sea-weeds.

If to a lixivium (washings) of the latter, or to the residual liquor of salt-pans, in which sea-water has been evaporated for the purpose of obtaining common salt, a solution of chlorine in water be added, a deep yellow colour and a peculiar odour will be produced. By distillation and passing the vapour over a salt, called muriate of lime, which detains the watery part, a few drops may be obtained of a red colour, very volatile and filling the receiver with vapours like those of nitrous acid: or, after passing chlorine into the above-named lixivia, they may be shaken up with some ether, which will dissolve the bromine; from which it will acquire a hyacinth tint, and float upon the surface. Upon agitating this solution with caustic potash, it immediately yields up the bromine to it; and the process may be repeated with the same ether: and

* From a Greek word, signifying "a strong disagreeable odour."

thus by alternately using the ether and potash, the new substance may be separated from a large portion of water. The bromine is extracted from the potash, by treating it with sulphuric acid, diluted with half its weight of water, and oxide of manganese; in an analogous way to that by which chlorine is obtained from sea salt.—(§ 83.) It is given off by distillation in red vapours, which condense into blackish red drops in the receiver, which should be kept cool.

(§ 101.) Bromine is a fluid of a hyacinth-red colour, when viewed by light transmitted through thin strata. At a temperature a few degrees below 0° it suddenly congeals and is very brittle. Its odour is extremely disagreeable and intense; its taste unpleasant and very powerful. It corrodes the skin and colours it yellow, but not permanently; it is very poisonous; its specific gravity is nearly 3; it is very volatile; gives off red vapours at common temperatures, and boils at $116^{\circ}.5$.

A taper will not burn in its vapour, but it alters the tint of the flame in air.

It is soluble in water, alcohol, and particularly in ether.

It does not redden, but destroys the colour of litmus, and even of indigo.

BROMINE AND OXYGEN.

Bromic Acid.—115. (1 B. 75 + 5 O. 40.)

(§ 102.) BROMINE may be obtained in union with oxygen, in the form of an acid, by adding sulphuric acid to a solution of a salt, which will be hereafter described, called Bromate of Barytes, as as long as any precipitate is produced.

Bromic acid in solution has scarcely any odour, but possesses an acid taste and reddens, and gradually destroys the blue colour of litmus. It is probably a compound of

1 equivalent of bromine . . .	75
5 ditto of oxygen	40

and its number 115

It is therefore similar in its nature to the chloric and nitric acids.

BROMINE AND HYDROGEN.

Hydro-bromic Acid.—76.

(1 B. 75 + 1 H. 1.)

(§ 103.) HYDROGEN mixed with the vapour of bromine, and exposed to the light of the sun, undergoes no change; but on introducing a lighted candle, or a red-hot iron into the mixture, combi-

nation ensues in the vicinity of the heated body, but not with explosion. A colourless gas, possessed of acid properties, is thus generated, and it has been distinguished by the name of hydro-bromic acid.

It is rapidly absorbed by water, but may be preserved over mercury. It may be abundantly produced from a mixture of bromine and phosphorus, slightly moistened. It produces dense white vapours in the air from its combination with the steam, and it possesses a strong irritating odour. The solution in water is colourless, and possesses the principal properties of the gas.

The hydro-bromic acid is decomposed by chlorine, which combines with its hydrogen, forming muriatic acid, and the bromine is set free.

The decomposition of hydro-bromic acid, by substances which combine with its bromine, affords half the volume of pure hydrogen. Hence its composition is

1 equivalent of bromine . . .	75
1 ditto of hydrogen	1

and its equivalent 76

It is therefore analogous in its composition to muriatic acid.

BROMINE AND CHLORINE.

Chloride of Bromine.

(§ 104.) BY passing chlorine through bromine, and condensing the vapours which arise at a low temperature, a reddish-yellow fluid may be obtained with a very penetrating odour and disagreeable taste. It is very fluid and volatile. Metals in a finely-divided state take fire in its vapour. The solution of this compound in water has strong bleaching powers.

IODINE*.—124.

(§ 105.) IODINE is another undecomposed substance, which has lately been extracted from the ashes of sea weeds, or the substance called *kelp*, which is largely produced on the western coasts of Scotland, and used for making soap. Its discovery preceded that of bromine, and, like it, its properties bear a strong analogy to those of chlorine. It is a very remarkable fact, although no useful inference has yet been drawn from the remark, that the three most electro-negative bodies, next to oxygen,

* From a Greek word signifying "Violet-coloured."

connected as they likewise are by common properties, exist almost exclusively in the ocean and its immediate productions.

The soluble part of *kelp*, or the ashes of sea-weeds dissolved in water, afford upon evaporation a salt called carbonate of soda; and after its extraction, an uncrystallizable residue remains. When sulphuric acid is poured upon this, in a retort furnished with a receiver, beautiful violet vapours make their appearance, which are condensed in crystalline plates of the colour and lustre of plumbago (commonly known as black lead). These crystals may be collected and dried between folds of blotting-paper. The addition of a small quantity of oxide of manganese facilitates the process of extraction.

(§ 106.) Iodine, thus obtained, is a solid, at the ordinary temperature of the atmosphere, in the shape of scales or plates of regular forms. Its colour is dark-grey; and it possesses a metallic lustre. It is soft and friable, and may easily be rubbed to a fine powder. Its taste is hot and acrid, but it is very sparingly soluble in water. It is poisonous in large doses, but has been used in medicine. At 60° of Fahrenheit, it is nearly five times as heavy as water. It produces a yellow stain upon the skin, which speedily evaporates. It fuses at 225° , and assumes the elastic form, under the pressure of the atmosphere, at about 350° . In this state, when it is of a beautiful purple colour, it is 124 times heavier than hydrogen; and as it combines with that element in equal volumes, this number represents the weight of its combining proportion, or equivalent.

It has the property of forming an insoluble compound with starch, of a beautiful blue colour; and its presence may thus be detected in very minute proportions.

IODINE AND OXYGEN.

Iodic Acid.—164. (1 I. 124 + 5 O. 40.)

(§ 107.) IODINE is not altered by being heated in oxygen gas; but when it is exposed to protoxide of chlorine (§ 88), which holds this element by a very slight attraction, there is an immediate action; its colour changes to a bright orange, and a liquid is formed. By the application of a gentle heat, an orange compound of iodine and chlorine is evaporated, and a compound of iodine and oxygen remains.

(§ 108.) It is a white semi-transparent solid, without smell, but with a strong astringent, sour taste. It may be called iodic acid.

It is decomposed by heat, and the sole products are iodine and oxygen: 13 grains afford 9.25 cubic inches of the latter gas, or by weight 3.15 grains. Hence it is composed of

1 equivalent of iodine	124
5 ditto of oxygen	40

and its number is 164

Its composition is therefore analogous to that of chloric acid. It is soluble in water, and its solution first reddens, and then destroys, blue vegetable colours.

Iodic acid, when mixed with charcoal, sugar, sulphur, and other combustible bodies, detonates upon the application of heat. The solution corrodes all metals, and even acts upon gold and platinum.

IODINE AND CHLORINE.

(§ 109.) IODINE absorbs chlorine, and forms with it an acid solid compound, whose nature is not yet perfectly understood.

IODINE AND HYDROGEN.

Hydriodic Acid.—125. (1 I. 124 + H. 1.)

(§ 110.) WHEN iodine is heated in hydrogen gas, an expansion of volume takes place; an acid gas is formed which is rapidly absorbed by water, and is acted upon by mercury so readily, that it cannot be long preserved over that metal.

The same gaseous compound is produced in abundance by the action of moistened iodine and phosphorus on each other. The oxygen of the water combines with the phosphorus, and the hydrogen with the iodine. The mixture may be distilled in a retort, and the gas received into a vessel filled with common air, which, by a proper arrangement, it will expel by its superior gravity. It has been called hydriodic acid.

(§ 111.) The gas is colourless; has a very sour taste, and pungent odour; and reddens blue vegetable colours, without ultimately bleaching them.

It is decomposed by mercury, which unites with the iodine, and leaves half the original volume of pure hydrogen; it is therefore a compound of equal volumes of iodine, in its elastic state, and hydrogen.

Now 50 cubic inches of iodine	Grains,
have been found to weigh .	131.3
50 ditto of hydrogen . . .	1.05

which would make the weight
of 100 cubic inches of hy-
driodic acid . . . 132.35

and this agrees very nearly with direct
experiment. Its composition by weight is
1 equivalent of iodine . . . 124
1 ditto hydrogen . . . 1

and its number . . . 125

The solution of hydriodic acid in water is fuming, and, when saturated, has a density of 1.7. It does not act upon mercury, although in the gaseous state it attacks it so powerfully. Chlorine takes the hydrogen from this compound; muriatic acid is formed, and iodine liberated.

IODINE AND NITROGEN.

Iodide of Nitrogen.

(§ 112.) IODINE and nitrogen cannot be made to unite directly: but if iodine be kept in a solution of ammonia in water, the latter is decomposed; its hydrogen unites with part of the iodine, and its nitrogen with another part. The latter compound is precipitated in the form of a brownish black substance, which is the iodide of nitrogen.

(§ 113.) Like the chloride of the same element (§ 95), it is highly explosive. It detonates violently, as soon as it is dry; and the slightest pressure produces the same effect even when moist. It is supposed to consist of

3 equivalents of iodine . . .	372
1 ditto of nitrogen . . .	14
	386

But all attempts to collect the products of its detonation with accuracy have failed.

Iodine and Bromine.

(§ 114.) IODINE appears to form two compounds with bromine; the first is a solid, which, when heated, gives off reddish brown vapours; the second is formed by a further proportion of iodine, and is a dark-coloured liquid. Their properties have not been minutely examined.

It is a curious fact, that chlorine takes hydrogen from bromine, and bromine

from iodine; but the affinities of these three bodies for oxygen are in the inverse order.

SULPHUR.—16.

(§ 115.) SULPHUR is one of the few elements which occur in nature in their simple form. It is a well known mineral substance, found in large quantities in the neighbourhood of volcanoes; and, as an article of commerce, is chiefly brought from the Mediterranean. It is also extracted for use from some of its compounds. It is commonly met with in two forms—that of a compact, brittle solid; and that of a fine powder. It is of a light yellow colour; and when melted emits a peculiar odour. It is insoluble in water, and tasteless. It is about double the weight of water, its specific gravity being 1.98. It is readily melted and volatilized, and begins to evaporate at 170°, and to fuse at 105°. At 220° it becomes completely fluid; but possesses the peculiar property of solidifying at a higher degree, or at 350°, and of again melting by a reduction of temperature. It sublimes (this term is used to denote the evaporation of a solid) at 600°; and condenses into the form of a powder, or, as it is termed, of *flowers*. When poured into water, in the state of complete fusion, it becomes of the consistency of wax, and assumes a red colour: it may then be used for taking impressions from engraved stones, and hardens upon cooling.

Sulphur is completely soluble in boiling oil of turpentine, and in alcohol, when the two substances are brought in contact in the state of vapour. It is inflammable; that is to say, it combines, when ignited, with the oxygen of the atmosphere with the evolution of light and heat. It burns with a faint blue light, at a temperature of about 180° or 190°; and the evolution of heat is so small, that it may be burned out of gunpowder, of which it is one of the principle ingredients, without inflaming it. At a temperature of 300°, however, its combustion is more rapid.

SULPHUR AND OXYGEN.

Sulphurous Acid.—32.

(1 S. 16 + 2 O. 16).

(§ 116.) WHEN sulphur is burned in dry oxygen-gas, there is no increase in volume; but at common temperature and pressure, a colourless transparent gas is formed, which is distinguished from all other elastic fluids, by a suffo-

eating pungent odour, well known as the smell of burning brimstone. It may be obtained by the action of sulphuric acid upon mercury, in a state of great purity. The mixture may be put into a retort and heated, but the gas must be received over mercury.

It is called sulphurous acid gas.

(§ 117.) It extinguishes all burning bodies, when immersed in it, and cannot itself be burned. It is instantly fatal to animal life. It assumes the liquid form under a pressure not exceeding that of two atmospheres; or at the degree of cold produced by a mixture of snow, or pounded ice, and salt.

It first reddens blue vegetable colours, and then destroys them; and its bleaching powers are very considerable. The vapours of burning sulphur are much used in whitening silk and straw-work.

One hundred cubic inches of sulphurous acid weigh 67.5: which is exactly double the weight of an equal quantity of oxygen; so that the weights of sulphur and oxygen, in the compound, are equal; and, as there is reason to suppose, from data which will be hereafter specified, that it is composed of two equivalents of oxygen and one of sulphur, the number of the latter must be 16.

Water at 60° dissolves about 33 times its bulk of sulphurous acid; and the solution possesses its peculiar odour and taste, which is astringent. It cannot, however, be preserved any length of time without change.

Sulphuric Acid.—40.

(1 S. 16 + 3 O. 24).

(§ 118.) A MIXTURE of sulphurous acid and oxygen gas may be kept for any length of time without showing any further disposition to combine, provided they are quite dry. If water be present, the sulphurous acid will gradually unite, with a further proportion of oxygen, and the compound, which is sulphuric acid, will be taken up by the water.

Sulphuric acid is an article of great importance, and is largely consumed in many manufactures; and there are several ways of procuring it for commerce.

By distilling, at a high heat, the salt called green vitriol (which, it will be hereafter seen, is a compound of sulphuric acid and protoxide of iron) a dense, oily, colourless liquid may be obtained; which emits white vapours on exposure to the air. If this liquid be again distilled, at a lower temperature,

into a receiver surrounded with pounded ice or snow, a transparent, colourless vapour will pass over, which will condense into a white crystalline solid. It is tough and elastic; liquefies at a temperature of 66°, and boils at about 110° or 120°. It has a strong affinity for water, and immediately takes it from the atmosphere. This solid body, there is reason to suppose, is pure *anhydrous* sulphuric acid; but there are some doubts respecting its nature.

The residue in the retort will be no longer fuming, and is the common oil of vitriol of commerce.

Hydro-sulphuric acid is also largely obtained by burning a mixture of about 8 parts of sulphur and 1 of nitre, in close leaden chambers, containing water. The fumes, as they rise, are dissolved; and the acid is procured in a concentrated state by evaporation of the solution. The hydro-sulphuric acid, or oil of vitriol, is a colourless, oily fluid, of a specific gravity, when most concentrated, of 1.85; at which density it contains about 81 per cent. of real acid. It boils at 620°, and freezes at 15°. It rapidly absorbs moisture from the air, and may be mixed with water in any proportion above that just stated.

(§ 119.) It is acrid, caustic, and intensely sour. It decomposes animal and vegetable substances rapidly; probably from its great affinity for water, which is an essential ingredient of their composition, and charcoal is produced. It often derives a brown tinge from small particles of this nature falling into it. It reddens blue vegetable colours, even when very largely diluted. When sulphuric acid is passed through a porcelain or platinum tube, heated to redness, it is decomposed, and two measures of sulphurous acid to one of oxygen are obtained. Its composition is therefore,

1 equivalent of sulphur . . .	16
3 ditto of oxygen . . .	24

—
and the number of the anhydrous acid is 40
—

If we add to these proportions 1 equivalent of water, we shall have for the composition of the hydro-sulphuric acid,

1 equivalent of sulphur . . .	16
3 ditto oxygen . . .	24
1 ditto water . . .	9

—
and its number 49
—

in which the water is in the same pro-

portion, 19 per cent., as in the acid of the specific gravity 1.85.

Hypo-Sulphurous Acid.—24.

(1 S. 16 + 1 O. 8.)

(§ 120.) WHEN iron filings are digested in a solution of sulphurous acid, they are dissolved without effervescence; the iron takes half the oxygen from the sulphur, and an acid is formed with the other half, which combines and forms a salt with the oxide of iron so produced.

This acid has been called the *hypo-sulphurous*, upon the principle of nomenclature before explained (§ 60.) It cannot be exhibited in a separate state; for at the moment of quitting the base with which it is united, it is resolved into sulphurous acid and sulphur. It is a compound of

1 equivalent of sulphur . . .	16
1 ditto of oxygen . . .	8

and its number is . . .	24
	—

Hypo-Sulphuric Acid.—72.

(2 S. 32 + 5 O. 40.)

(§ 121.) BY passing sulphurous acid through water, in which finely-pounded peroxide of manganese is suspended by agitation, the peroxide yields part of its oxygen to the acid, and converts one portion into sulphuric acid, and another into a peculiar acid, which has been called the *hypo-sulphuric*. The process for exhibiting the latter, in a separate form, is complicated, and we shall for the present postpone its consideration.

It is obtained in a liquid form, it reddens litmus paper, but has no smell, by which it is distinguished from sulphurous acid; and it forms soluble salts with oxide of lead, and other substances, whose combinations with sulphuric acid are insoluble.

The results of its analysis shew it to be a compound of

2 equivalents of sulphur . . .	32
5 ditto of oxygen . . .	40

and its number is . . .	72
	—

SULPHUR AND HYDROGEN.

Sulphuretted Hydrogen.—17.

(1 S. 16 + 1 H. 1.)

(§ 122.) BY repeatedly subliming sul-

phur in hydrogen gas, a combination between the two elements takes place, without change of volume; and a gas is formed, to which the name of sulphuretted hydrogen has been given. It may be produced in abundance, by acting upon sulphuret of iron (which may be formed by melting together sulphur and iron filings) with sulphuric acid. It is quickly absorbed by water, but may be collected in glass bottles filled with that liquid, and provided with glass-stoppers, which must be inserted the moment they are filled with the gas.

(§ 123.) It is colourless and transparent. Its smell is very offensive, and resembling that of putrifying eggs, or the washings of a foul gun-barrel; its taste is acid.

It is highly poisonous, and a horse has been known to perish in an atmosphere which contained no more than 1-250th part of it.

It is inflammable; and, like hydrogen, burns either silently, or with explosion, according to the circumstances of its mixture with oxygen. It instantly extinguishes all burning bodies.

It tarnishes silver, gold, and mercury, and blackens white paint made with preparations of lead. Its solution in water acquires the taste and peculiar smell of the gas, and reddens blue vegetable colours. Some mineral waters, as those of Harrogate, are impregnated with this gas. Two measures of sulphuretted hydrogen require three of oxygen for their complete decomposition, one measure of which saturates the two of hydrogen, and the other two the sulphur; water and sulphurous acid are the products.

Now, 100 cubic inches of hydrogen weigh 2.11 grains, and 100 cubic inches of sulphuretted hydrogen 36 grains; and as the sulphur is taken up by the hydrogen without change of bulk, if we deduct the weight of the latter, the remainder 33.89 will be the weight of the sulphur, and 2.11 : 33.89 :: 1 : 16, which makes the equivalent of sulphur, as we before stated (§ 117) 16.

It follows also that sulphuretted hydrogen is composed of

1 equivalent of sulphur . . .	16
1 ditto hydrogen . . .	1

and that its number is . . .	17
	—

Bisulphuretted Hydrogen.—33.

(2 S. 32 + 1 H. 1.)

(§ 124.) A SECOND combination of sulphur with hydrogen is known, of which the proportion of sulphur is double that of the last compound. It may be produced as follows:—Boil together a strong solution of potash with flowers of sulphur, and gradually drop the product into muriatic acid; a small quantity of sulphuretted hydrogen will be given off, and an oil-like, adhesive, brown fluid, the *bisulphuretted hydrogen*, will fall to the bottom of the vessel: a large quantity of sulphur will, at the same time, be precipitated.

(§ 125.) Its smell and taste greatly resemble those of sulphuretted hydrogen: it is inflammable, and gives off fumes of sulphurous acid during its combustion. It is heavier than water, and many of its properties are analogous to those of acids. It may be decomposed by a gentle heat: sulphuretted hydrogen is given off, and sulphur remains.

SULPHUR AND CHLORINE.

Chloride of Sulphur.—52.

(1 S. 16 + 1 C. 36.)

(§ 126.) SULPHUR may be united directly with chlorine, by passing a current of the gas over it in a state of minute division, and at a gentle heat. Ten grains of the flowers will thus absorb nearly 30 cubic inches; which is nearly in the proportion of 16 to 36, the weights of the respective equivalents of the two bodies.

(§ 127.) Chloride of sulphur is a volatile fluid, of a red colour by reflected light, but green by transmitted light. It rises in vapour at a temperature below 200° ; and emits fumes which affect the eyes, and occasion a flow of tears. Its specific gravity is 1.6. It does not redden the colour of dry litmus paper; but, when shaken up with water, a kind of ebullition and great disengagement of heat take place; sulphur is precipitated, and the liquid is found to consist of a solution of muriatic, sulphurous, and sulphuric acids. In this process the water is decomposed; its hydrogen passing to the chlorine, and forming muriatic acid; and the oxygen to the sulphur, with which it forms the latter acids.

SULPHUR AND NITROGEN.

(§ 128.) THERE is no known compound of sulphur with nitrogen.

SULPHUR WITH BROMINE AND IODINE.

(§ 129.) SULPHUR unites directly with iodine at a gentle heat, and probably enters into a similar combination with bromine. The precise composition, however, of the compounds is unknown. The iodide of sulphur is a black, radiated solid, easily decomposable by heat: the iodine rising in vapour at a temperature but little above that at which the two bodies combine.

PHOSPHORUS.—12. ?

(§ 130.) PHOSPHORUS has never yet been found in nature in its simple form, but may be obtained by the following process, the explanation of which will be given upon a future occasion.

Take a quantity of bones that have been calcined (burnt in an open fire), reduce them to a fine powder, and digest them for two or three days with half their weight of concentrated sulphuric acid; adding as much water as may give the mixture the consistence of a thin paste. At the expiration of the time twice the bulk of boiling water must be stirred up with it, and the liquid separated by filtration. The solution, which will be very acid, is then to be evaporated to the thickness of syrup, mixed with one-fourth its weight of charcoal in powder, and strongly heated in an earthen retort; the beak of which must be plunged under water. The heat must be slowly raised till it becomes very intense. A large quantity of gas will escape during the process, and spontaneously inflame upon passing through the water into the air, and the phosphorus will distil over in drops, and congeal in the water. The process is troublesome, and not unaccompanied with danger in unskilful hands.

(§ 131.) Phosphorus, as thus obtained, is a soft solid, of a flesh-red colour; but, when purified by a second distillation, may be obtained colourless and perfectly transparent. Its specific gravity is 1.77. It is highly inflammable, and it is necessary to preserve it under water in well-closed bottles. It may be readily cut with a knife. When air is carefully excluded it melts at about 110° , and boils at 550° of Fahrenheit. In melting, it is necessary to keep it under water, to prevent it from bursting into flame. It may be set on fire by friction, as is commonly known from the phosphorus bottles, in which it is employed for the purpose of obtaining instantaneous light. It is tasteless, and

insoluble in water, but proves highly poisonous when taken into the stomach.

In the atmosphere, it emits a light smoke and peculiar smell, not unlike that of garlic; and a pale greenish, very beautiful light arises from it in the dark. This is owing to a slow combustion; and if a stick of phosphorus be confined in a jar full of common air over water, the whole of the oxygen will gradually disappear, and the nitrogen remain. It is soluble in oils, and communicates to them the property of shining in the dark. In pure nitrogen it is not luminous at any temperature.

There are some doubts with regard to the proportion in which this element enters into combination; owing to some peculiar difficulties in the analysis of its compounds. Such topics of controversy it is impossible for us, as we have before stated, to enter upon in a work like the present; but we must content ourselves with giving, in this and similar instances, that explanation of the facts which appears to us the best supported by the evidence.

PHOSPHORUS AND OXYGEN.

Phosphorous Acid.—20.

(1 P. 12+1 O. 8.)

(§ 132.) THE product of the slow combustion above described is a mixture of phosphorous and phosphoric acids, and may be obtained by placing two or three sticks of phosphorus in a funnel set upon an empty bottle: a highly acid liquid may thus be collected, consisting of a solution of the two acids in the water, which they attract from the atmosphere. No good process, however, is known by which they may be separated; and the pure phosphorous acid is best obtained by passing the vapour of phosphorus through a substance, before referred to (§ 23), called corrosive sublimate, heated in a glass tube. The liquid product is to be mixed with water, and heated till it becomes of the consistence of syrup. It is then a compound of pure phosphorous acid and water, which crystallizes on cooling. The process will be explained hereafter. When phosphorus is heated in highly rarefied air, a white powder forms upon it, which is volatile, and supposed to be the phosphorous acid in its anhydrous state: when heated in the open air, it takes fire, and it readily dissolves in water, to which it communicates an intensely sour taste.

(§ 133.) *Hydro-phosphorous acid* emits a disagreeable odour, and yields, when heated, penetrating white vapours. It has a strong tendency to unite with a further proportion of oxygen, which it absorbs slowly from the air, and becomes converted into phosphoric acid. The investigation of the composition of this acid is one of considerable difficulty; but the most probable inference from experiment is, that it is constituted of one equivalent of phosphorus, and one of oxygen, and that its number consequently is 20.

Phosphoric Acid.—28.

(1 P. 12+2 O. 16.)

(§ 134.) WE have already stated (§ 39) that phosphorus burns in oxygen gas with a splendour which the eye cannot bear. Its inflammation also in atmospheric air is brilliant and violent. In each case, copious white vapours are produced, which fall like snow to the bottom of the vessel in which the experiment is conducted. This is pure, anhydrous, phosphoric acid.

It may also be more conveniently formed by the action of phosphorus on nitric acid. Small fragments should be cautiously dropped into the acid, gently heated in a retort. The latter is decomposed; the action is very violent, and a large quantity of deutoxide of nitrogen is disengaged, a portion of the oxygen with which it was previously combined (§ 71) passing by elective affinity to the phosphorus. The solution obtained by this process is to be evaporated to dryness: in which state it consists of phosphoric acid, united with a proportion of water. Solid phosphoric acid may be united with water in any proportion beyond 20 per cent.; but, on heating the solution in a platinum vessel, the greater part of the water may be expelled: the residue fuses at a low red heat, and concretes on cooling into a kind of glass to which the name of *glacial phosphoric acid* was formerly given. It volatilizes unchanged at a high temperature, and is a compound of

3 equivalents phosphoric acid.	36
1 ditto of water	9

45

100 grains of phosphorus have been found, from the most careful experiments, to condense, by the first process, 135 grains of oxygen, which is very

nearly in the proportion of 12 to 16, or of

1 equivalent phosphorus . . .	12
2 ditto oxygen . . .	16
	—
	28
	—

It is a deliquescent substance, and dissolves in water, with a hissing noise. It is inodorous, very sour, and volatile at a bright red heat.

The acid obtained by the decomposition of bones for the manufacture of phosphorus, as above described (§ 130), consists of phosphoric acid, which in that process is decomposed by the charcoal; giving up its oxygen to superior affinity, at a high temperature, and disengaging the inflammable element.

Hypo-phosphorous Acid.—32.

(2 P. 24 + 1 O. 8.)

(§ 135.) A third compound of phosphorus and oxygen may be formed, by acting upon water with a substance, hereafter to be described, called *phosphuret of barytes*. An insoluble precipitate is formed, from which the liquid is to be separated by filtration. To this solution sulphuric acid is carefully added as long as any precipitate is formed. The sour liquid which remains, after a second filtration, is to be concentrated by evaporation, when a viscous, uncrySTALLIZABLE, acid fluid will be obtained, to which the name of hypo-phosphorous acid (§ 60) has been given. Its analysis proves that it contains less oxygen than the phosphorous acid, and that it is most probably a compound of

2 equivalents of phosphorus . . .	24
1 ditto of oxygen . . .	8
	—
	32
	—

PHOSPHORUS AND HYDROGEN.

Proto-phosphuretted Hydrogen—14*.

(1 P. 12 + 2 H. 2).

(§ 136.) WHEN the solid hydro-phosphorous acid (§ 132) is heated in close vessels, out of the contact of the air, a large quantity of gaseous fluid is given off, and may be collected in the usual way over water; which, however, absorbs about one-eighth of its volume. By this process, the water in the hydro-phosphorous acid is decomposed: part of the phosphorus combines with a

further portion of oxygen at its expense, and becomes converted into phosphoric acid; while another portion unites with the hydrogen, and forms the proto-phosphuretted hydrogen.

(§ 137.) This gas is colourless, and possesses a very disagreeable smell. It does not spontaneously inflame when brought into contact with atmospheric air; but when mixed with it, or pure oxygen, it detonates violently with the electric spark, or when heated to 300° of Fah. 100 cubic inches weigh about 29.5 grs. One part of it in volume requires two parts of oxygen for its complete combustion; one volume of which unites with the hydrogen, which, in the compound, is condensed into half its bulk, and the remaining volume unites with the phosphorus, and forms phosphoric acid. Its constitution therefore is

1 equivalent phosphorus . . .	12
2 ditto hydrogen . . .	2
	—
	14
	—

The condensation of the two volumes of hydrogen into one, may be shewn by heating sulphur in this gas: decomposition ensues, a double volume of sulphuretted hydrogen is produced, and a combination of sulphur and phosphorus precipitated.

Per-phosphuretted Hydrogen.—13.

(1 P. 12 + 1 H. 1).

(§ 138.) A SECOND compound of phosphorus and hydrogen may be obtained in the following manner:—Into five parts of water put half a part of phosphorus cut very small; add one part of granulated zinc, and three parts of strong sulphuric acid. The gas will be disengaged in small bubbles, which spontaneously take fire as they reach the air upon the surface of the fluid. This is a very beautiful experiment. The gas may also be obtained by boiling phosphorus in a small retort, with a hot solution of potash, which should entirely fill the vessel. The neck of the retort being made to dip into a small bowl filled with the same solution, the gas, as it is extricated, gradually expels the liquid from the neck, and inflames when allowed to escape into the air; or may be collected in small quantities under a bell glass, also filled with the alkaline solution. Some caution is required in collecting the gas for examination; and at the commencement

* The prefixes *proto* and *per* denote the lowest and highest degree in which one body unites with another.

of the process, it should be generated very slowly, that any air contained in the apparatus may not be too suddenly decomposed.

(§ 139.) Perphosphuretted hydrogen is a colourless gas, possessing a highly offensive smell, resembling that of garlic. It is very slightly soluble in water: 100 cubic inches of it weigh about 27.5 grains.

Its most peculiar property is that of spontaneously inflaming on mixture with air or oxygen gas. This inflammation is accompanied by a very beautiful appearance. After the explosion, a circular, horizontal ring of dense white smoke rises in the air, which preserves its form for a long time, and increases its diameter as it ascends. Phosphoric acid and water are the products of its combustion. It deposits phosphorus when allowed to stand some time in a glass receiver, and may be resolved into its elements by passing through it a succession of electric sparks: phosphorus is precipitated and an equal bulk of pure hydrogen remains.

If, therefore, from the weight of 100 cubic inches of perphosphuretted hydrogen 27.5 grains, we deduct the weight of an equal bulk of hydrogen, 2.1 grains, (§ 41), the remainder 25.4 will be the weight of the phosphorus in the compound: which is very nearly in proportion of the two equivalents

1 equivalent phosphorus .	12
1 ditto hydrogen . .	1
	—
	13
	—

When sulphur is heated in this gas an equal volume only of sulphuretted hydrogen is the result.

PHOSPHORUS AND CHLORINE.

Proto-chloride of Phosphorus.—48.

(1 P. 12 + 1 C. 36).

(§ 140.) WE have already stated (§ 132) that, by passing the vapour of phosphorus over corrosive sublimate heated in a glass tube, a liquid product is obtained: this is a combination of phosphorus and chlorine.

(§ 141.) It is transparent and colourless, of the specific gravity of 1.45. It does not affect the colour of dry litmus paper; but the fumes, which it gives off in abundance, are acid, owing to the contact with the moisture of the atmosphere. It acts energetically upon water; the hydrogen combining with the chlorine and form-

ing muriatic acid, and the oxygen with the phosphorus, by which the phosphorous acid is produced as before described (§ 132); in which process the muriatic acid is driven off by heat, and pure phosphorous acid remains.

From the most careful experiments it appears, that the proto-chloride of phosphorus is a compound of

1 equivalent phosphorus .	12
1 ditto chlorine . .	36
	—
	48
	—

Per-chloride of Phosphorus.—84.

(1 P. 12 + 2 C. 72.)

(§ 142.) WHEN phosphorus is introduced into chlorine it inflames spontaneously, and burns with a pale flame. The product is a white solid, which condenses upon the sides of the vessel.

(§ 143.) It is volatile at a temperature below 212° ; but may be fused under pressure, and crystallizes in cooling. It acts with violence upon water, forming with its elements muriatic and phosphoric acids.

One grain of phosphorus unites with six of chlorine, when burned in that gas; which is in the exact proportion of

1 equivalent phosphorus .	12
2 ditto chlorine . .	72
	—
	84
	—

PHOSPHORUS AND IODINE.

Iodide of Phosphorus.

(§ 144.) PHOSPHORUS and iodine very readily enter into combination by mere contact in the cold: during their action on each other much heat is given out; but the nature of the product has not been minutely examined. When the iodide is thrown into water, hydriodic and phosphoric acids are formed, and it is by this process that the former is best obtained, (§ 110.)

PHOSPHORUS AND SULPHUR.

Phosphuret of Sulphur.

(§ 145.) PHOSPHORUS and sulphur act with great violence on each other, and, it is probable, give rise to various compounds, in different proportions, which have not been completely examined. The combination may be effected by agitation under water, the temperature of which should not exceed 140° or 160° of Fahrenheit. The compound has a reddish-brown colour, and is fluid about

40° of Fahrenheit, or at the average temperature of the atmosphere. It does not act on water. It is more inflammable than phosphorus, and forms a good composition for phosphoric fire-matches. It may be distilled unchanged at a strong heat.

(§ 146.) It may here be stated, that the chemical nomenclature which designates the binary compounds of substances of the electro-negative class, which are not acid, by the termination *ide*, as *oxide*, *chloride*, *bromide*, &c., distinguishes by the termination *uret* analogous combinations of substances of the electro-positive class, which are not of a metallic nature. Thus we have *phosphuret*, *sulphuret*, *carburet*, &c.; the further application of which we shall become acquainted with as we proceed.

SELENIUM.—40.

(§ 147.) SELENIUM is another of those rare substances, hitherto undecomposed, with which the rapid progress of chemistry has lately made us acquainted. Neither the utility nor the interest of the subject will require us to describe at length the combinations of an element which many accomplished chemists have never had an opportunity of seeing.

In the process for obtaining sulphuric acid at Fahlun in Sweden, from a natural combination of sulphur and iron, called pyrites, it was observed, that a reddish mass was deposited, which, in burning, gave out a peculiar odour. The principal portion of the mass was sulphur; but with it was mixed a very minute quantity of the substance to which the name of *selenium* has been given. Selenium, at common temperatures, is a brittle solid of a brown colour and metallic fracture: it has neither taste nor smell. When pounded, the particles stick together, and its powder has a deep red colour. It melts at a few degrees above the boiling point of water; and, when warm, is very ductile, and may be drawn into fine threads; which are red by transmitted, but grey by reflected light. It boils at a temperature of about 600°, and condenses either in opaque metallic drops, or, when large vessels are used, in flowers of the colour of cinnabar. Its vapour has a deep yellow colour. When heated in the flame of a candle, urged by a current of air from a blow-pipe, it emits a strong smell of horse-radish.

SELENIUM AND OXYGEN.

Selenic Acid.—56. (1 S. 40 + 2 O. 16.)

(§ 148.) THE peculiar smell of horse-radish arises from the combination of selenium with oxygen, which is formed by heating this substance in contact with atmospheric air: this is probably an oxide of selenium. But when selenium is dissolved in nitric acid, and the solution evaporated, so as to expel the excess of that acid, a white saline mass remains, which may be sublimed by raising the temperature, the colour of the vapour closely resembling that of chlorine. The selenic acid crystallizes in needles in the colder part of the apparatus.

(§ 149.) Selenic acid has a sour, and slightly burning, taste: it is very soluble both in water and alcohol. It is readily decomposed by all substances which have a strong attraction for oxygen. If sulphurous acid be passed into its solution, pure selenium will be thrown down in the state of a red powder, and sulphuric acid formed. It may be likewise precipitated by the immersion of plates of zinc or polished iron.

Selenic acid is composed of

1 equivalent of selenium	40
2 ditto of oxygen	16
	—
	56

CHAPTER IV.

On the Non-Metallic Fixed Elements—Carbon, Silicon, and Boron; and their Binary Compounds.

(§ 150.) FOLLOWING up the arrangement which we have adopted as convenient, and with the hopes that, from its strong contrasts, it will be easily retained by the memory, we come now to a class of substances which are totally unaffected by any changes of temperature, to which the art of man has yet been able to expose them, and are only known in the solid form: they can be neither fused nor volatilized, and are, therefore, designated as *fixed*. They have been called Carbon, Silicon, and Boron: they are bad conductors of heat, and the first alone (and that not in its purest form) is a conductor of electricity.

After describing the mode of obtaining each of these substances and its distinctive characters, we shall describe such of its known binary combinations, with the preceding elements, as possess any interest, either from their striking properties, their illustrations of the laws

of chemical affinity, or their application to the arts.

CARBON.—6.

(§ 151.) CARBON, although but rarely met with pure and uncombined, is one of the most important elements in nature: its various compounds are more generally and abundantly distributed than those of any other substance, and it may be said to form the basis of the whole organic creation.

Carbon is well known by the names of *diamond* and *charcoal*, which two substances, although so different and almost opposite in *physical* characters, it is probable, from the most unexceptionable experiments, are *chemically* the same.

(§ 152.) Diamonds have been chiefly found in the East Indies and Brazil, disseminated in gravel or imbedded in sand-stone. They are considered as gems of the highest value. Their crystalline texture gives them a degree of hardness which is beyond that of any other known substance. They are transparent, and of various colours; and their specific gravity varies from 3.4 to 3.6. Diamond, when subjected to the most intense heat in close vessels, undergoes no change; but, if strongly heated in the open air, is entirely consumed. If this experiment be made in pure oxygen gas, the diamond will be burnt, the oxygen will disappear, and an equal bulk of carbonic acid gas remain, whose properties will be presently described. The product of the combustion is precisely the same as that of an equal weight of pure charcoal under the same circumstances.

(§ 153.) Charcoal may be obtained free from impurity, by burying pieces of wood in sand in a crucible or other convenient vessel, and exposing them for about an hour to a very intense heat. It is prepared, in the large way, by the distillation of wood in cast-iron cylinders; or, more roughly, by building up piles of wood in a pyramidal form, covering them over with clay or other earth, and leaving a few air-holes, which are closed as soon as the masses are well lighted. It may be also procured in the state of an impalpable powder, by passing the vapour of alcohol through a tube heated to redness.

Charcoal, formed from wood, is a black, brittle solid, easily pulverized, perfectly insipid, and free from smell. It is insoluble, and is unchanged by any degree of heat in close vessels. It burns

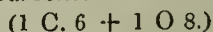
readily in atmospheric air, and with great splendour in oxygen gas: the product being pure carbonic acid and a little water; the latter arising from a minute proportion of hydrogen, which the charcoal retains with great obstinacy.

Fresh prepared charcoal has the property of absorbing a considerable quantity of the different gaseous bodies, amounting in some cases to 80 or 90 times its own volume. The quantity of this absorption appears to depend upon the original elasticity of the gases; those which possess this property in the highest degree, and have hitherto resisted all attempts to convert them into liquids by compression, are taken up in the smallest proportion, while those which have been so condensed are absorbed more freely. Of hydrogen gas it will absorb only 1.75 times its own volume, but of ammoniacal gas 90 times.

Charcoal possesses the singular property of resisting the putrefaction of animal substances; and meat which has become tainted may even have its sweetness restored by rubbing with charcoal, and may be long preserved sweet by being buried in its powder. It also produces the remarkable effect of destroying the colour and smell of many animal and vegetable substances. Common vinegar, by being boiled with it, becomes perfectly colourless; and red wines, rum, or brandy may be bleached by filtration through it. It is largely employed, for this purpose, in the process of sugar refining, and for preparing colourless crystals of citric acid and other vegetable productions. Charcoal prepared by calcining animal substances in close vessels, has been found most efficacious for these purposes.

CARBON AND OXYGEN.

Carbonic Oxide.—14.



(§ 154.) IF we introduce into a gun-barrel, or retort, a mixture of equal parts of well-dried chalk and charcoal pulverised, and expose it to a strong heat, a large quantity of gaseous matter will be produced, which may be collected over the water bath. The product must be agitated with lime-water, and a considerable absorption will take place, after which the remaining gas will be carbonic oxide. In this process, iron or zinc filings may be substituted for the charcoal, with greater certainty of procuring the gas perfectly pure.

(§ 155.) Carbonic oxide is a gaseous body of an offensive smell, colourless, and insipid. It is a very little lighter than atmospheric air; 100 cubic inches weighing 29.65 grains. It is very sparingly soluble in water, and it does not in any way affect the colour of blue vegetable infusions. It is inflammable, and burns with a blue flame; but a lighted taper plunged into a jar full of the gas is instantly extinguished. No water is formed during its combustion, as may be ascertained by holding a cold bell-glass over its flame, which will remain bright and free from the dew which is instantly deposited by the combustion of hydrogen gas and its compounds under similar circumstances. It is noxious to animal life when received into the lungs; and, when respired for a few minutes, produces giddiness and fainting.

If carbonic oxide be mingled with an equal bulk of hydrogen, and passed through an ignited tube, the tube will become lined with charcoal, and water will be formed; as at a high temperature the hydrogen attracts oxygen with more force than carbon. When mixed with half its volume of oxygen, it may be exploded in a detonating tube by the electric spark, and 150 measures of the mixture will thus be converted into 100 of carbonic acid, a combination which will be described in the next section; after which the calculation will be better understood, from which its composition has been inferred to be

1 equivalent of carbon . . .	6
1 ditto of oxygen . . .	8
	—
	14

The blue flame which may be observed over burning charcoal arises from the combustion of this gas.

Carbonic Acid.—22.

(1 C. 6 + 2 O. 16.)

(§ 156.) We have just seen (§§ 152, 153) that diamond and charcoal may both be burnt in oxygen: the bulk of the gas is not altered, but its weight is increased by the exact amount lost by the solids during the combustion; and all its properties are changed. Carbonic acid, however, is most conveniently obtained by dropping fragments of marble or chalk into muriatic acid, diluted with two or three times its weight of water. A strong effervescence ensues, the gas from which may be collected over the water-bath.

(§ 157.) Carbonic acid gas is colourless and inodorous. It is rather more than by one-half heavier than common air; 100 cubic inches weighing 46.5 grains. It is perfectly unflammable, and instantly extinguishes flame. From its great specific gravity, it will remain for some time at the bottom of a jar with its mouth turned upwards; and may be poured from one such vessel into another like water. It is an amusing experiment to place a lighted taper in the bottom of the jar, as it will be instantly extinguished by pouring the gas upon it, like a liquid.

It is speedily fatal to animals which breathe it: and hence the danger of exposure to the fumes of burning charcoal, which have in so many instances proved fatal. From its great density, it also not unfrequently collects in the bottoms of wells and mines, while the upper parts are free from it, and, from its injurious effects, is called by the miners *choak damp*. It has been condensed into a liquid by a pressure amounting to that of 36 atmospheres, or a column of mercury 90 feet in height.

Water, under common circumstances of pressure and temperature, will dissolve about its own bulk of this gas; but the quantity taken up may be increased by pressure, and will, in fact, be in exact proportion to the compressing force. It is by the strong compression of a forcing-pump that the common soda-water is so highly charged with this gas.

The solution has an agreeable subacid taste, and reddens paper, stained with the blue colour of litmus. When, however, an infusion of litmus, which has been reddened by this acid, is boiled, the blue colour returns as the acid escapes: an effect which distinguishes it from all other bodies of the same class. The pleasant pungency of brisk and sparkling fermented liquors is owing to the carbonic acid which they hold in solution, and which they lose upon exposure to the air, and become thereby flat and stale.

Carbonic acid is produced in all the common cases of combustion, and is likewise abundantly formed during the respiration of animals; it is not, therefore, surprising that it should be always present in the atmosphere to the amount of about one-thousandth or one-fifteen-hundredth of its bulk. Indeed, the great wonder is, considering the abundance of its sources, that it does not accumu-

late to an injurious degree, as it certainly would, without one of those admirable and providential compensations which perpetually strike us amongst the laws of nature, and which we shall hereafter find in the vegetable part of the creation; by which it is provided, that the process of vegetation should remove the contamination produced by the animal part.

As it has been proved that oxygen, in uniting with carbon to form carbonic acid, does not alter its volume, it is easy to deduce the constitution of this body from its weight :

	Grains.
If from the weight of 100 cubic inches	46.5
we deduct the weight of 100 cubic inches of oxygen	33.8
the remainder	12.7
will be the weight of the carbon in the compound; and the proportion of 33.8 to 12.7 is very nearly the same as 16 to 6, or	
1 equivalent of carbon	6
2 ditto of oxygen	16
making the equivalent of carbonic acid	22

When a succession of electrical sparks is passed through carbonic acid gas, confined over mercury, a portion is converted into carbonic oxide and oxygen; and when a stream of it is passed over charcoal, ignited in a porcelain tube, it is wholly converted into carbonic oxide.

It will now be understood, that as carbonic oxide becomes converted into carbonic acid, by explosion with half its bulk of oxygen, and as the oxygen in carbonic acid is equal in volume to the acid, the quantity of oxygen in the former compound is exactly half that in the latter, and the composition of the oxide must be as before stated (§ 155.)

1 equivalent carbon	6
1 ditto oxygen	8
equivalent of carbonic oxide	14

CARBON AND HYDROGEN.

Sub-carburetted Hydrogen.—8.

(1 C. 6 + 2 H. 2.)

(§ 158.) By stirring the bottom of any stagnant pool of water, especially if it consist of clay containing vegetable substances in a state of decomposition, a quantity of gaseous matter will be disengaged, which may be collected in an inverted bottle, provided with a funnel.

This, after being washed with lime-water, or a solution of potash, will consist of sub-carburetted hydrogen nearly in a state of purity.

(§ 159.) It is a colourless, permanent gas, soluble in very minute proportions in water, with very little odour, and inflammable. When set on fire it burns with a yellow flame, and gives out much more light than hydrogen: 100 cubic inches weigh 16.94 grains.

When mixed with atmospheric air or oxygen, in certain proportions, it explodes with violence upon contact with flame.

To decompose it completely, it is necessary to mix it with rather more than twice its bulk of oxygen gas; but exactly two volumes are consumed. Water and a quantity of carbonic acid are produced, the latter being precisely equal to the original bulk of the inflammable gas. Now, as carbonic acid contains its own bulk of oxygen (§ 156), half the oxygen in the above experiment must be taken up by the formation of that body: the other volume would require, to convert it into water, two volumes of hydrogen (§ 46): two volumes of hydrogen must, therefore, have been present in the volume of the sub-carburetted hydrogen originally employed.

Deducting, therefore, from the weight of 100 cubic inches of this gas 16.9 the weight of 200 cubic inches

hydrogen	4.2 (§ 41)
the remainder	12.7

will be the weight of carbon in the compound; and the proportions 12.7 : 4.2 approach very nearly to those of

1 equivalent carbon	6
2 ditto hydrogen	2
	8

The fire-damp of coal-mines almost wholly consists of this gas, and the dreadful explosions which so often prove destructive to human life are occasioned by the ignition of its mixtures with atmospheric air at the candles of the miners.

It is necessary here to state that, when sub-carburetted hydrogen and chlorine are mixed together over water, no action takes place if light be carefully excluded; but if exposed to the light of day, and still more rapidly in the light of the sun, a series of decompositions ensues. Muriatic and carbonic

acids are formed, the former of which is instantly absorbed.

Carburetted Hydrogen.—14.

(2 C. 12 + 2 H. 2.)

(§ 160.) By gently heating, in a glass retort, three measures of strong sulphuric acid and one measure of alcohol, or pure spirits of wine, the mixture becomes black and thick, and a copious disengagement of gaseous matter takes place, which may be collected over water: after agitation with lime-water, or solution of potash, pure carburetted hydrogen remains.

(§ 161.) It is colourless, possesses very little smell, and is slightly soluble in water. It is inflammable, and burns with a dense bright flame, giving out much more light than the sub-carburetted hydrogen. It is very little lighter than common air, 100 cubic inches, weighing 29.65 grains. When mingled with oxygen gas and ignited, it explodes with great noise and violence. To insure its complete combustion, it should be mixed with five times its volume, of which, however, three only are taken up by the combustion. If too little oxygen be used, much of the charcoal is precipitated unburned. The products are water and two volumes of carbonic acid, indicating double the quantity of carbon in the preceding compound. The composition, therefore, of carburetted hydrogen is as follows:—

2 equivalents carbon . .	12
2 ditto hydrogen . .	2
	—
	14

the two volumes of hydrogen, as with the sub-carburet, being condensed into one.

Its specific gravity exactly agrees with this calculation; for 100 cubic inches, by the above decomposition, give 200 cubic inches of carbonic acid, which weigh 93 grains (§ 157)
from which, deduct- }
ing the weight of 200 } 67.6 (§ 37)
cubic inches oxygen }

the remainder, . . . 25.4, will be the weight of carbon in 100 cubic inches of the gas; and if to . . . 25.4
we add the weight of 200 }
cubic inches of hydrogen } 4.2 (§ 41)

the total 29.6
will be the weight of 100 cubic inches of carburetted hydrogen, as we have just stated.

The condensation of the hydrogen

may be proved in another way: carburetted hydrogen, like phosphuretted hydrogen (§ 137), may be decomposed by single elective affinity with sulphur, which has a greater attraction for hydrogen than carbon. If, therefore, we heat sulphur in a measure of the gas over mercury, carbon will be precipitated, and two measures of sulphuretted hydrogen will be obtained: hydrogen, as we have seen (§ 122), not having its volume changed by combination with sulphur.

(§ 162.) The detonation of these gases with oxygen, which is extremely violent, would not be unaccompanied with danger in the apparatus which was formerly described (§ 46); but may be securely and accurately effected by the following simple means:—A strong glass tube must be provided, of the interior diameter of from two-tenths to four-tenths of an inch; it must be bent in the form of a syphon, with legs of nearly equal length: one end must be hermetically sealed (closed by the heat of a lamp urged with a blow-pipe), and the other open, and a little enlarged, in the manner of a funnel. Two platina wires must be inserted close to the sealed extremity, by which an electrical spark may be passed. The closed end must be graduated by the successive introduction of equal weights of mercury, and marking upon the glass the space which they occupy.

The syphon must be filled with water, or, in cases where the gases may be absorbable by that fluid, with mercury; and a portion of the gases, previously mixed with great accuracy, may easily be introduced above the fluid in the sealed end of the tube. It must next be removed from the trough in which it has been filled, by applying a finger upon the orifice. The fluid may be adjusted to the same level in the two legs, by either adding a few drops or expelling some, by the immersion of a piece of wood. The volume of the included gas must next be accurately measured by the graduation. The finger is now to be replaced upon the orifice, and a portion of air will be included between it and the fluid; which, when the electrical spark is passed, and the explosion takes place, acts as a spring, the column of included mercury recoiling against it, and preserving the tube from fracture. Even when the detonation is strongest, nothing is felt but a slight pressure upon the finger, which, after the process, must be gently removed,

and the fluid again adjusted till it stands at equal heights in the two legs, when the residual gas may be measured with the greatest nicety.

(§ 163.) Carburetted hydrogen may be decomposed by passing it through red-hot tubes: at a low-red heat charcoal is deposited, and an equal volume of sub-carburetted hydrogen produced; but at a white heat the latter is also decomposed, and the gas is greatly increased in volume. Chlorine readily combines with this gas, even in the dark; and in this way a mixture of carburetted and sub-carburetted hydrogen may readily be separated. (§ 159.) The result of the combination is a yellow liquid, like oil, possessing a peculiar sweet taste and ethereal smell: it is volatile, and may be distilled without change. It may properly be distinguished by the name of *hydro-carburet of chlorine*. From the property of forming this oily substance, carburetted hydrogen was formerly called *olefiant gas*.

(§ 164.) All the common, but highly interesting phenomena of *flame*, are dependent upon the combustible gases which we have just been examining; and the important processes of artificial illumination are founded upon their properties. Flame is, in all cases, the combustion of explosive mixtures of inflammable gases or vapours with common air in different proportions; and, when continuous, is maintained by an uninterrupted flow of these elastic fluids into the atmosphere, with which they slowly mingle. That it cannot be regarded as mere combustion at the point of contact, may be proved by holding a taper within a large flame produced from alcohol: the flame of the taper will appear within the other, from which it will be distinguished by its difference of colour; proving, that there is oxygen even in its interior. The flames of lamps and candles are fed by a stream of inflammable gases and vapours, arising from the decomposition of wax, tallow, or oils; commenced by the application of heat from some exterior source, but continued by the high temperature which is kept up by the process itself. The quantity of light which flame emits is dependent upon the incandescence of minute particles of solid matter, which are thrown off during the combustion; and those flames, whose products are only gaseous matter, give very little light. The light

of a stream of ignited hydrogen is scarcely visible in the day-light; but if a small coil of platinum wire be suspended in it, or some solid body in very fine powder, such as the oxide of zinc be projected through it, it becomes very luminous. Phosphorus burns in chlorine with a very pale flame, the product of the combustion being a very volatile substance (§ 143); but burned in oxygen it emits a most splendid light, owing to the ignition of the particles of solid phosphoric acid which are given off. Carburetted hydrogen gives out, during its combustion, much more light than the sub-carburetted, owing to the larger quantity of carbon which is disengaged; but if the mixture with oxygen be in such proportions as at once to burn the whole of the charcoal in its gaseous combinations, without previous deposition, the light becomes blue, and is greatly reduced in intensity. These different stages of combustion may all be observed in the flame of a common candle; at the bottom part, where the inflammable gases are given off in the smallest quantity, and where they are most intimately mixed with the air, the combustion is at once complete, and the light is blue and faint; the centre part, where the particles of charcoal, owing to a less admixture of oxygen, are thrown off in a solid state and become incandescent before they are finally burnt, is white and highly brilliant; and the upper, where the charcoal is in still greater quantity and much of it finally escapes combustion, is red and dull.

The heat of flames, even of those which give least light, as of hydrogen and spirits of wine, is intense; as is shewn by platinum wire becoming white hot in the parts where the combustion is perfect. The fact is also proved by certain instances, where combustion takes place without evolving sufficient heat to cause inflammation, as in the instance of the *flameless lamp* already referred to, (§ 31). This experiment may be varied by pouring a little ether into the bottom of a wide-mouthed glass; when, if a piece of heated platinum wire be held a little above its surface, it will become red-hot, but will not inflame the ether till it acquires a full white heat.

(§ 165.) Upon the necessity of an intense heat for the maintenance of flame is founded the properties of the *miner's safety lamp*, by which the oc-

currence of those dreadful explosions, to which we have just referred (§ 159), has become much less frequent; and might most probably be wholly prevented, were it not for gross carelessness and some still remaining prejudice. In this beautiful contrivance, the flame of the lamp is covered with a tall cylinder of wire-gauze, securely screwed to it, which does not prevent the circulation of the air, and, from the fineness of its texture, obstructs but little light. The operation of the metallic gauze may be illustrated by bringing a piece of it down upon the flame of a candle or of coal-gas. The flame may thus, as it were, be cut in half; the lower part only remaining ignited, the upper being cooled below the constituent temperature of inflammation: that the cooled gaseous matter, however, passes through the tissue may be proved, by lighting it again upon the upper surface. Now, supposing an explosive mixture to penetrate to the flame of the lamp, protected in the manner which we have just described, it will burn within the wire-boundary which has been prescribed to it; but the cooling influence of the gauze will prevent its extension to the external atmosphere, and thus all danger is avoided. The safety of the lamp, of course, entirely depends upon the perfect state of the wire-tissue and the manner in which it is secured, so that no aperture may exist by which the flame may pass.

(§ 166.) The progress of science has lately introduced a great improvement in the art of illumination, by suggesting the decomposition of the different substances which yield the inflammable gases in establishments formed for the purpose, and conducting the pure elastic products through pipes to the situations where they are required to be burned; and where their consumption may be regulated to the greatest nicety, according to circumstances. Coal, oil, and rosin have been chiefly employed in this new manufacture; and that upon a scale which cannot but astonish those who recollect the first suggestion of a scheme, which was very generally deemed chimerical. Coal, when subjected to distillation in close vessels, at a red heat, gives out a large quantity of gas, consisting chiefly of sub-carburetted hydrogen, mixed with the other inflammable gases which we have just described. The sulphuretted hydrogen with which it is contaminated is removed, by passing it through lime, suspended in water by

agitation. The specific gravity of well-purified coal-gas varies from 450 to 700. A large quantity of an impure carbon, called coke, is found in the retorts after the extraction of the gas.

Oil, by being allowed to trickle into a red-hot retort, half filled with coke or pieces of brick to increase the heated surface, is decomposed, and yields a large quantity of gas, which is much richer in carburetted hydrogen than coal-gas, and is, therefore, much better fitted for purposes of illumination. Its specific gravity varies from 800 to 950. It contains no admixture of sulphuretted hydrogen, and requires no purification; and as less of it is required for any given quantity of light, the atmosphere of a room is less heated and contaminated by its combustion. It is, however, considerably more expensive than the gas from coal; although the first outlay of capital for a manufactory upon a large scale is less on account of the smaller size of the necessary pipes and apparatus. Rosin, it has lately been discovered, by peculiar treatment, also yields an abundance of gas, equal in quality to that from oil, and at about one-fourth the expense: its smell, moreover, is much less offensive than that of either coal or oil-gas, and it has been introduced with success into several very large establishments. Wood is likewise capable of yielding inflammable gas, by distillation, in abundance; but it is so deficient in the compounds of carbon and hydrogen, as to be nearly worthless for illumination. In manufactories, however, of charcoal, in iron retorts for the making of gunpowder, the gas which is given off is led by a pipe under the cylinders, and is economically employed in maintaining their heat.

The sub-carburetted and carburetted hydrogen gases are the only compounds of carbon and hydrogen known, which assume the form of permanently elastic fluids. There are, however, a variety of other combinations of these two elements, in different proportions, which have not been clearly developed, some of which are the products of art and others of nature, the description of which we shall defer to a future occasion.

CARBON AND CHLORINE,

Per-chloride of Carbon.—120.

(2 C. 12 + 3 Chl. 108.)

(§ 167.) THE union of carbon with

chlorine cannot be directly effected; and no action ensues upon strongly heating charcoal in that gas. We have, however, seen (§ 163), that a triple compound of carbon, hydrogen, and chlorine may be produced by the direct combination of carburetted hydrogen and chlorine. If this oily liquid be exposed to the direct rays of the sun, in an atmosphere of chlorine, it will be decomposed; muriatic acid will be produced by the abstraction of the hydrogen, and the carbon will attach itself to another portion of the chlorine. The experiment is not difficult of performance in a glass retort fitted with a stop-cock. The muriatic acid is absorbed, as it is formed by the admission of a little water and fresh chlorine, admitted as required.

(§ 168.) The per-chloride of carbon is a transparent, colourless solid, having very little taste, and possessing an aromatic odour, resembling that of camphor. Its specific gravity is 2. It is very brittle, and a non-conductor of electricity. It is volatile at common temperatures, and is sublimed in very transparent, colourless crystals. It melts at 320° , and boils at 360° Fahrenheit. It is scarcely combustible; but when held in the flame of a spirit-lamp, it burns with a red flame, and gives off much smoke and fumes of muriatic acid. It is little soluble in water, but is readily taken up by alcohol, and may be crystallized from that fluid on evaporation. It is also soluble in ether and oils. The results, both of its analysis and synthesis, concur in its being a compound of 2 equivalents of carbon . 12

3 ditto chlorine . . . 108

—
120

Chloride of Carbon.—42.

(1 C. 6 + 1 Chl. 36.)

(§ 169.) WHEN the vapour of the per-chloride of carbon is passed through an ignited glass tube containing fragments of glass or rock-crystal, to increase the heated surface, it is partly decomposed; chlorine escapes, and a fluid passes over, which may be separately condensed.

(§ 170.) It is limpid and colourless; does not assume the solid form even at 0° Fahrenheit, and is volatilized at a temperature between 160° and 170° . Its specific gravity is about 1.5. It may be distilled without change, but undergoes decomposition at a red heat. It may be mixed with alcohol, ether, and oils, but

not with water. It is not combustible except when held in the flame of a lamp, when it burns with a yellow light, and gives off much smoke, mixed with acid fumes. Its analysis shows it to be a compound of

1 equivalent of carbon . . 6
1 ditto chlorine . 36
—
42

Sub-chloride of Carbon.—48.

(2 C. 12 + 1 Chl. 36.)

(§ 171.) ANOTHER compound of carbon and chlorine has been accidentally formed, in very small quantities, in a manufactory of nitric acid, from nitre and vitriol, in Sweden. It was in the form of white feathery crystals, rather heavier than water, and insoluble in that fluid. It had a peculiar smell, resembling spermaceti, and was tasteless. It was soluble in alcohol and ether, and burned in the flame of a lamp with a greenish colour. It was decomposed into chlorine and carbon, by passing its vapour through a glass tube containing fragments of rock-crystal, heated red hot. It was ascertained to be composed of

2 equivalents of carbon . 12
1 ditto chlorine . 36
—
48

CARBON AND NITROGEN.

Carburet of Nitrogen, or Cyanogen.—26.

(2 C. 12 + N. 14.)

(§ 172.) By boiling together red oxide of mercury with twice its weight of the well-known colour called *Prussian blue*, in a sufficient quantity of water, a compound may be obtained which crystallizes in prisms, and which was formerly known by the name of prussiate of mercury, but is now designated as *cyanuret of mercury*. This substance well dried at a temperature below that of boiling water, when put into a small retort, or such a tube as that before described (§ 36), and exposed to heat, blackens and liquefies, and gives off a gas which may be collected over mercury.

(§ 173.) The carburet of nitrogen is a permanently elastic fluid at a common pressure and temperatures. Its smell is pungent and disagreeable. It is colourless, and burns with a purplish-blue flame, but extinguishes burning bodies. One hundred cubic inches of it weigh about 55 grains. It is soluble in water

and alcohol, the former of which takes up about four and a half times its volume, and the latter twenty-three times. It has been reduced to the liquid state by a pressure equivalent to that of 3.6 atmospheres.

When mixed with oxygen it may be exploded by the electric spark. It requires twice its volume of that gas for its complete combustion; and the products are two volumes of carbonic acid and one volume of nitrogen. Now, 200 cubic inches of carbonic acid contain, as we have seen (§ 161), 25.4 grains of carbon, and 100 cubic inches of nitrogen weigh 29.7 grains, making the weight of 100 cubic inches of cyanogen 55.1 grains, and agreeing very closely with its weight, as before stated, from experiment; there is, therefore, no difficulty in concluding that it is a compound of

2 equivalents carbon . .	12
1 ditto nitrogen . .	14
—	—

and that its combining proportion is } 26

The carburet of nitrogen, although a compound body, has the singular property of combining with elementary substances in a manner perfectly analogous to that of the simple gaseous bodies which we have previously examined. Thus, like chlorine, it forms acids by combining both with oxygen and hydrogen; and it is on account of this analogy that the appellation of *cyanogen** has been conferred upon it. The consideration of these *triple* compounds we must refer to a future chapter. We may here remark that carbon is, of all the elementary substances, the only one which is disposed to form *triple* combinations. One of these we have described in the *hydro-carburet of chlorine* (§ 163). The combinations of cyanogen (termed cyanurets) afford other instances of this tendency, and we shall find that they abound in the products of the animal and vegetable parts of creation.

CARBON AND SULPHUR.

Sulphuret of Carbon.—38.

(1 C. 6 + 2 S. 32.)

(§ 174.) CARBON and sulphur may be made to combine by the following process:—Place an earthen tube, of about

an inch and a half diameter, a little inclined, across a chafing-dish, and nearly fill it with small pieces of charcoal well burned, and quite free from moisture. To the higher end adapt a glass tube filled with small pieces of sulphur, which may be pushed forward by means of a wire passing through a cork, which must be made carefully to exclude the air. To the opposite end a bent glass tube must be adjusted, which must pass down below the surface of some water contained in a bottle. When the fire in the chafing-dish has been lighted, and the centre of the tube become red hot, the sulphur must be thrust forward into contact with the ignited charcoal; and immediately bubbles of gas will escape from under the water in the bottle, and a vapour will appear which will condense under the water into a liquid. It may be rectified, or obtained quite pure, by re-distilling it at a heat not exceeding 110° Fah., in a glass retort containing a little muriate of lime (or chloride of calcium), to retain any water with which it may be mixed.

(§ 175.) The sulphuret of carbon thus obtained is a perfectly colourless and transparent fluid. Its taste is acrid, pungent, and somewhat aromatic: its smell nauseous and fetid in a very high degree. It is very volatile, and boils at common atmospheric pressure at a temperature not exceeding 110° Fah. It has never been congealed by the lowest artificial temperature. It is highly inflammable, and it burns with a blue flame, emitting copious fumes of sulphurous acid. No moisture whatever is deposited upon cold glass during its combustion, which is sufficient proof that it contains no hydrogen. It mixes readily with alcohol and ether, but not with water; the latter precipitates it from either of the former mixtures. Owing to its extreme volatility, it has been employed to produce great degrees of cold. A thermometer whose bulb has been covered with lint, and moistened with it, will sink rapidly from 60° to 0° Fah.; and, by a little management under the exhausted receiver of an air-pump, may be made to fall to even 70° or 80° below 0°; so that mercury may be readily frozen by its evaporation. The results of a careful analysis prove this remarkable fluid to be composed of

1 equivalent of carbon . .	6
2 ditto sulphur . .	32
—	—

* From two Greek words, signifying the formation of blue: the termination in *gen*, shewing its reference to hydrogen, oxygen, &c.

SILICON.—8.?

(§ 176.) ALTHOUGH silicon, in combination with oxygen, is one of the most abundant substances in nature, so much so as to entitle it to be considered the basis of the inorganic, as carbon is of the organic, creation, it is only very lately that the art of chemistry has succeeded in separating it in small quantities, by difficult and complicated processes. These are dependent upon the properties of substances which have not yet been described, and which are themselves of extraordinary character, and we shall therefore defer the details of its extraction till they can be better understood.

(§ 177.) Silicon has been obtained in the form of a solid, in a disintegrated state, of a dark brown colour, and without metallic lustre. It does not conduct electricity, and is incombustible either in air or oxygen gas. It may be exposed to the strongest heat without fusing or undergoing any other change. It decomposes water, and becomes converted into oxide of silicon, or silex, by union with its oxygen. Although much uncertainty still prevails in all experiments with this difficultly-obtained element, there is reason to suppose that, in the state of oxide, it is combined with its own weight of oxygen, and that its equivalent is 8.

SILICON AND OXYGEN.

Oxide of Silicon or Silex.—16.

(1 S. 8+1 O. 8.)

(§ 178.) SILEX enters into the composition of most earthy minerals, and exists in a state of almost perfect purity, in the form of colourless rock-crystal or crystals of quartz. By heating these substances red-hot, and throwing them into water, they may be disintegrated and reduced to fine powder, by pounding. Sufficiently pure silex may also be obtained by calcining common flints at a low red heat. They may then be easily reduced to powder. In this state they must be mixed with four times their weight of carbonate of potash, and fused in a crucible, by a strong red heat. A strong effervescence will take place; after which the heat must be urged till the materials enter into complete and quiet fusion. The compound may be dissolved, when cold, in water; and the alkaline solution, after filtration, dropped gradually into diluted sulphuric or muriatic acid. An abundant precipitate will

subside, which, after pouring off the liquid which covers it, must be thoroughly washed till the water comes away perfectly tasteless: it must then be dried.

(§ 179.) Silex thus obtained is a perfectly white and tasteless powder, which feels harsh between the fingers. Its specific gravity is 2.6. It is insoluble in water, and is not acted upon by any acid except the fluoric, whose properties will be hereafter described. When first prepared, and minutely divided, it is taken up by solutions of pure potash or soda, but not by the volatile alkali ammonia.

(§ 180.) Silex, in combination with the fixed alkalies, forms the basis of that inestimable product of art—glass. When one part of very pure sand is ignited with three of carbonate of potash, a compound is formed, which is very soluble, and deliquesces (attracts moisture) in the air. When these proportions are reversed, and three parts of sand and one of carbonate of potash are fused together, the product is insoluble in water and all the acids except the fluoric, and possesses the well-known properties of glass. Its purity depends upon the purity of the ingredients employed in its manufacture. Green bottle-glass is made of impure materials; such as sand, which contains a considerable proportion of iron, and the commonest kind of soda, called kelp. Window-glass is made of pure alkali, and sand which is free from iron; and for plate-glass the utmost care is taken to provide both the materials in their purest forms.

BORON.—6.?

(§ 181.) WHEN equal parts of the metal *potassium*, and very pure boracic acid, are heated together in a copper tube, at a temperature of about 302° Fahrenheit, they suddenly become red hot: the metal disappears, and, when the product has been washed with warm water, a greenish-brown or olive-coloured substance is obtained, which is boron.

(§ 182.) It is insoluble in water, tasteless, and does not affect the colour of blue vegetables. It may be exposed to the strongest heat in close vessels without undergoing any change; but when heated to about 600° Fahrenheit in the open air, it burns vividly, absorbs oxygen, and is converted into boracic acid. It is a non-conductor of electricity.

BORON AND OXYGEN.

Boracic Acid.—22.

(1 B. 6 + 2 O. 16.)

(§ 183.) THERE is considerable discrepancy in the results of experiments upon the quantity of oxygen which is absorbed by boron during its combustion; but there is reason to think that 100 grains condense 266.6 grains of that gas, which is in the proportion of 6 to 16: so that, supposing the acid to be a compound of two equivalents of oxygen, the number for boron will be 6, and that for the acid 22. Boracic acid may be obtained by dissolving a given weight of a salt called *borax* (which is imported from India in a rough state under the name of *tincal*) in boiling water; and adding half its weight of sulphuric acid, previously diluted with an equal quantity of water. Upon evaporation of the solution and cooling, shining, scaly crystals will be precipitated, which is the substance in question. It is also found native in the neighbourhood of volcanoes.

(§ 184.) It is destitute of smell, and possesses very little taste. It is sparingly soluble in water, and the solution reddens vegetable blue colours; and, what is very singular, it also reddens the yellow colour of turmeric in the manner of alkalies. It is soluble in alcohol, and communicates a beautiful green colour to its flame. It fuses when heated, and gives off its water of crystallization to the amount of about 44 parts in the

hundred. It is therefore probable that the crystallized acid is composed of

1 equivalent acid	.	.	22
2 ditto of water	.	.	18
			—
			40
			—

CHAPTER V.

On the further Combinations of the preceding Acids and Salifiable Base: or Salts of Ammonia.

(§ 185.) As it is by no means our object to compile a system of chemistry for proficient in the science, in which order and perfect arrangement would be one of the most essential considerations, but rather to lead the mind of the student by degrees from the simpler to understand the more complex phenomena of Nature, we here deem it right to pause, and offer a brief retrospect of the progress which we have made; from which it may be hoped, that the facts already stated, and which it is of the utmost importance to recollect with readiness, may be more surely fixed upon the mind. Our attention has hitherto been directed to the properties of twelve *non-metallic elements*, or substances, which have resisted all attempts to decompose them, and their binary compounds with one another. The arrangement which we have adopted with regard to the former, and the simple equivalent proportions in which they combine together, will readily be recalled by the means of the following Table:—

TABLE I.

NON-METALLIC ELEMENTS.

	Electro-Negative.	Equivalents.	Electro-Positive.	Equivalents.
Aëriform..	Oxygen	8	Hydrogen	1
			Nitrogen	14
	Chlorine	36		
Volatile...	Bromine	75		
	Iodine	124		
			Sulphur	16
			Phosphorus	12
Fixed ....	. . . . .		Selenium	40
			Carbon.	6
			Silicon	8
			Boron	6

In Table II. we have arranged the binary compounds of the foregoing element in three divisions, viz., the Acid, the Alkaline or Basic, and the Neutral. The proportions in which they are combined

is stated, and the equivalent number of each compound is added to it, shewing in what proportion it would enter into any further combination.

TABLE II.

BINARY COMPOUNDS OF THE NON-METALLIC ELEMENTS.

Equivalents.		Equivalents.	Acid. Electro-Negative.	Equivalents.	ALKALINE OR BASIC. Electro-Positive.	Equivalents.	NEUTRAL.	Equivalents.
1 Hydrogen	+ 1 Oxygen						Water	9
Ditto	+ 2 Ditto						Peroxide of Hydrogen	17
1 Nitrogen	+ 1 Oxygen						Protoxide of Nitrogen	22
Ditto	+ 2 Ditto						Deutoxide of Nitrogen	30
Ditto	+ 3 Ditto		Hypo-Nitrous Acid	38				
Ditto	+ 4 Ditto		Nitrous Acid	46				
Ditto	+ 5 Ditto		Nitric Acid.	54				
Ditto	+ 1 Hydrogen				Ammonia	17		
1 Chlorine	+ 1 Oxygen						Protoxide of Chlorine	44
Ditto	+ 4 Ditto						Peroxide of Ditto	68
Ditto	+ 5 Ditto		Chloric Acid	76				
Ditto	+ 8 Ditto		Per-Chloric Acid	100				
Ditto	+ 1 Hydrogen		Muriatic Acid	37				
4 Ditto	+ 1 Nitrogen						Chloride of Nitrogen	158
1 Bromine	+ 5 Oxygen		Bromic Acid	115				
Ditto	+ 1 Hydrogen		Hydro-Bromic Acid	76				
1 Iodine	+ 5 Oxygen		Iodic Acid	164				
Ditto	+ 1 Hydrogen		Hydriodic Acid	125				
3 Ditto	+ 1 Nitrogen						Iodide of Nitrogen	396
1 Sulphur	+ 2 Oxygen		Sulphurous Acid.	32				
Ditto	+ 3 Ditto		Sulphuric Acid	40				
Ditto	+ 1 Ditto		Hypo-Sulphurous Acid	24				
2 Ditto	+ 5 Ditto		Hypo Sulphuric Acid	12				
1 Ditto	+ 1 Hydrogen		Sulphuretted Hydrogen	17				
2 Ditto	+ 1 Ditto		Bisulphuretted Ditto	33				
1 Ditto	+ 1 Chlorine						Chloride of Sulphur	52
1 Phosphorus	+ 1 Oxygen		Phosphorous Acid	20				
Ditto	+ 2 Ditto		Phosphoric Acid	28				
2 Ditto	+ 1 Ditto		Hypo-phosphorous Acid	32				
1 Ditto	+ 2 Hydrogen						Proto-phosphuretted Hydrogen	14
1 Ditto	+ 1 Ditto						Per-phosphuretted Hydrogen	13
1 Ditto	+ 1 Chlorine						Proto Chloride of Phosphorus	48
1 Ditto	+ 2 Ditto						Per-Chloride of Ditto	54
1 Selenium	+ 2 Oxygen		Selenio Acid	56				
1 Carbon	+ 1 Oxygen						Carbonic Oxide	14
1 Ditto	+ 2 Ditto		Carbonic Acid	22				
1 Ditto	+ 2 Hydrogen						Sub-Carburetted Hydrogen	8
2 Ditto	+ 2 Ditto						Carburetted Hydrogen	14
1 Ditto	+ 1 Chlorine						Chloride of Carbon	42
2 Ditto	+ 3 Ditto						Per-Chloride of Carbon	120
2 Ditto	+ 1 Ditto						Sub-Chloride of Carbon	48
2 Ditto	+ 1 Nitrogen						Cyanogen	26
1 Ditto	+ 2 Sulphur						Sulphuret of Carbon	38
1 Silicon	+ 1 Oxygen						Silex	16
1 Boron	+ 2 Oxygen		Boracic Acid	22				

(§ 186.) The union of substances of the first division with those of the second, (that is to say, of acids with bases), gives rise to a very important class of compounds, to which the general name of salts has been given. The chemical

nomenclature distinguishes them by changing into *ate* the termination of the acids ending in *ic*, or those which contain the largest proportion of oxygen (§ 60); and into *ite*, the termination in *ous* denoting an inferior proportion: as ni-

trate from nitric, nitrite from nitrous acid, or sulphate from sulphuric, and sulphite from sulphurous acid, and placing it before the name of the alkali, as the nitrate of ammonia, the sulphite of ammonia, &c. The general designation of *salifiable base* is also given to any body which forms a salt by combination with an acid.

The salifiable bases are not only distinguished by their property of saturating the acids, but also of being liberated from their combinations at the negative pole of the voltaic battery, when exposed to the repulsive power of electricity, while the acids appear at the positive pole.

The only salifiable base which is formed by the binary combinations of the non-metallic elements is ammonia, or, as it is sometimes called, the volatile alkali.

In the third division of the above table there are three compounds which enter, in the manner of elementary substances, into composition with other bodies; these are, water, silicic acid, and cyanogen. To this property of the latter body we have before alluded (§ 173), and the nature of its compounds will be hereafter more fully investigated.

Of the combination of water in definite proportions with other bodies, we have given examples as forming the *water of crystallization* in salts (§ 81), which is essential to their constitution as crystals; and as a necessary constituent of the hydro-acids, as the *hydro-nitric* (§ 72) and *hydro-sulphuric* acids (§ 118). To the remaining definite compounds of water with different *salifiable bases* the term *hydrates* has been applied. In most of them it loses its fluid form, becomes fixed, and is often retained by so powerful an affinity, as not to be separated by the application of the most violent heat: of this species of combination many examples will occur in the sequel.

With regard to the third neutral body, silicic acid, the nature of its union with other substances is less understood than that of any other class of compounds. They are chiefly found in the mineral kingdom, and will be carefully examined when we come to treat of the *analysis of minerals*. It has sometimes been ranked with the acids, or electro-negative compounds, on account of its affinities being chiefly exerted upon different bases hereafter to be described.

Its few artificial combinations, of which glass is the most important, but which, according to the account which we have already given of its composition (§ 180), we are not at present warranted in classing with the definite compounds, will be noticed in the succession of the different bodies with which it unites.

Before we continue our account of the simple substances, by proceeding to enumerate the properties of the metallic elements, we deem it most conducive to our purpose, to describe the combination of the preceding acids with ammonia, and briefly to point out the properties of such of the salts of this base as possess any interest, or whose composition is sufficiently understood.

It may, perhaps, be objected to this arrangement, that we shall thus separate the ammoniacal salts from the great class of saline bodies, which are generally and conveniently arranged together; but, independently of certain peculiarities which might authorise such a separation, and which will be hereafter pointed out, we deem it justified by the facilities which it affords for illustration, and for the gradual application of the first elements of the science, of which it is our principal aim to render the acquirement as easy as possible.

The preceding details having strongly illustrated the fundamental law of chemical composition, that the equivalent numbers of the simple substances, or their multiples, are preserved in all their combinations with each other, the no less important remark will now be established, that when any body is compounded of two or more elements, and enters into union with another body, the sum of the equivalents of such elements will give the number denoting the proportion in which it will so combine (§ 27): a strong confirmation is thus incidentally afforded of the value of the equivalents previously determined.

(§ 187.) The salts of ammonia are distinguished as a class, by being all volatile, or decomposable by a strong heat. If the acid with which this base is combined be volatile, the salt will be sublimed without change; but if it be fixed, the ammonia will fly off, and the acid remain. Their taste is, in general, hot and biting; and they all emit the well-known smell of the volatile alkali, when mixed with caustic lime.

Nitrate of Ammonia.—*Anhydrous* 71,
Crystallized 80.

(1 N. 54 + 1 A. 17 + 1 W. 9.)

(§ 188.) THE composition and decomposition of this salt have been already described, for the purpose of illustration (§ 80). It readily deliquesces (attracts moisture from the air); and its most important property is that of yielding the protoxide of nitrogen when decomposed by heat (§ 61).

Muriate of Ammonia.—*Anhydrous* 54,
Crystallized 63.

(1 M. 37 + 1 A. 17 + 1 W. 9.)

(§ 189.) MURIATE of ammonia may be formed by mixing, over mercury, equal volumes of ammonia and muriatic acid gases, which will be entirely condensed into a white solid, which is the anhydrous salt; or it may be produced by neutralizing a solution of ammonia with solution of muriatic acid. Upon evaporation, the salt will be obtained in crystals containing, in addition, one equivalent of water. It is in this state that it is found in commerce under the name of *sal ammoniac*; and it is manufactured in abundance, by a complicated process, from bones and other refuse animal matters.

The salt possesses a pungent saline taste: it is readily soluble in water, producing a considerable reduction of temperature; and boiling water dissolves more than cold, the excess being deposited in crystals as the solution cools. It sublimes, without undergoing any change, at a temperature below redness. It may be passed, without alteration, through glass or earthenware tubes heated to redness; but, when transmitted over ignited metals, it is resolved into its gaseous elements.

The action of chlorine upon ammonia affords a singularly beautiful instance of the play of chemical affinities. When these two gases are suddenly mixed, they act so powerfully on each other, that a flash of white light accompanies the mixture; and when in the proportion of one part of the former to three of the latter, muriate of ammonia and nitrogen are the products. The chlorine takes hydrogen from one portion of the ammonia, liberating its nitrogen, and forms muriatic acid, which combines with the remainder of the ammonia to produce the salt. The experiment is very striking, and not difficult of performance in a

rough way. For this purpose two wide-mouthed bottles may be fitted together, by grinding, in such a way that one may stand inverted upon the mouth of the other. One of these may be filled with chlorine, and placed with its mouth upwards, covered with a ground disk of glass. The other may be filled with ammonia, by holding it over a tube proceeding from another bottle containing a mixture of sal ammoniac and lime heated. The ammonia, as it rises, will displace the common air, and it may be known to be full by the escape of the pungent gas. The bottle may then be carefully placed, with its mouth always kept downwards, upon the bottle of chlorine, after removing the disk of glass, and the position of the two dexterously reversed. The heavy chlorine and the light ammonia will rush in opposite directions, and unite with the extrication of flame.

Muriate of ammonia is used in the arts for various purposes, and, amongst others, for preventing the oxidation of the surface of copper in tinning. The *aqua regia* of commerce, for the solution of gold, is formed by dissolving *sal ammoniac* in nitric acid.

Hydriodate of Ammonia.—142.

(1 H. 124 + 1 A. 17.)

(§ 190.) WE have shown (§ 112) that when iodine is kept in a solution of ammonia, a new elective affinity is brought into action; part of it unites with the nitrogen of that compound, and is precipitated in the form of a brown powder, while another part combines with the hydrogen, and produces the hydriodic acid, which further neutralizes any excess of the alkali, and forms hydriodate of ammonia. This salt may also be formed by mixing the aqueous solutions of the acid and the base. It crystallizes in the form of cubes; is more soluble than the muriate of ammonia; and, like it, may be sublimed in close vessels without change. It is composed of equal volumes of hydriodic acid and ammoniacal gases.

Sulphite of Ammonia.

Anhydrous 49.—(1 S. 32 + 1 A. 17.)

Crystallized 107.—(2 S. 64 + 2 A. 34 + 1 W. 9.)

(§ 191.) THIS salt may be produced by the direct combination of its acid and base. It crystallizes in prisms; its taste is cool, and leaves a flavour of sulphur

in the mouth. It is soluble in its own weight of cold water, producing a considerable depression of temperature. Its solubility increases with heat, and a saturated boiling solution crystallizes on cooling. It rapidly attracts moisture and oxygen from the air, and is soon converted into a sulphate.

Sulphate of Ammonia.

Dry 66.—(1 S. 40 + 1 A. 17 + 1 W. 9.)

Crystallized 75.—(1 S. 40 + 1 A. 17 + 2 W. 18.)

(§ 192.) THIS salt may be formed by neutralizing ammonia with sulphuric acid, or by the decomposition of either the muriate or carbonate of ammonia by the same acid, which has a superior affinity for the base. It crystallizes in small prisms; has a sharp bitter taste; is soluble in twice its weight of cold, and in its own weight of boiling water; and slowly attracts moisture from the air. The crystals contain two equivalents of water, one of which may be expelled by careful drying, but the other cannot be driven off without decomposing the salt. It is chiefly used for the manufacture of *sal ammoniac*, which is obtained by sublimation from a mixture of sulphate of ammonia and common salt.

Hydrosulphate of Ammonia.*—34.

(1 H. 17 + 1 A. 17.)

(§ 193.) WHEN currents of sulphuretted hydrogen and ammonia are made to pass together into a vessel kept cool by ice, they combine, and the product crystallizes in transparent, colourless needles. This salt is probably composed of an equivalent of each ingredient. It is very volatile, and, when kept in glass, gradually sublimes to the top of the vessel. The same salt may be obtained in solution, by passing a current of sulphuretted hydrogen into liquid ammonia. It assumes very soon a greenish-yellow colour. It is much employed, as will be hereafter seen, as a test for metals in solution.

Carbonate of Ammonia.—39.

(1 C. 22 + 1 A. 17.)

(§ 194.) WHEN dry carbonic acid is

mixed over mercury with twice its volume of ammonia, complete condensation takes place, and a dry, white, volatile powder is produced. The taste and smell of this salt are the same as those of ammonia, but not so pungent. It converts the blue colour of vegetables to green. Hot water dissolves its own weight of it, and it is soluble in rather less than twice its weight of cold water. It speedily evaporates when heated; and when long kept, the ammonia escapes, and the residual salt is found to contain a larger proportion of carbonic acid.

Bicarbonate of Ammonia.

Crystallized 79.

(2 C. 44 + 1 A. 17 + 2 W. 18.)

(§ 195.) WHEN a current of carbonic acid gas is made to pass through a solution of carbonate of ammonia, the base unites with a further equivalent of the acid, and a distinct salt is formed. When the solution is gently evaporated, it may be obtained in crystals, which have no smell, and very little taste. The same salt is also formed when gaseous carbonic acid and ammonia are made to act on each other *when water is present*. This liquid so far overcomes the elasticity of the gas, which prevents any further combination, when unopposed, as to enable it to unite with another equivalent of the acid; affording an illustration of the general observation which we have made (§§ 3, 15), that the repulsive power prevailing in æriform fluids is opposed to chemical attraction.

(§ 196.) Salts which are thus constituted of two equivalents of their acid are distinguished by the Greek numeral *Bi* (two) prefixed to their names.

Sesqui-Carbonate of Ammonia.

Crystallized 118.

(3 C. 66 + 2 A. 34 + 2 W. 18.)

(§ 197.) ANOTHER compound of carbonic acid and ammonia is known, and commonly met with in commerce, under the name of carbonate of ammonia. It is obtained, by sublimation, from a mixture of muriate of ammonia and chalk. When fresh prepared it is of a crystalline texture, and semi-transparent, hard and compact. Its smell is pungent; its taste penetrating; and it affects the blue colours of vegetables in the manner of alkalis. Analysis has proved it to be a compound of carbonic acid and ammonia, in the proportion of three equivalent

* The chemical nomenclature is imperfect with regard to those acids into the composition of which hydrogen essentially enters; inasmuch as the prefix *hydro* is likewise employed to distinguish certain acids in combination with water (§ 72) from the same acids in an anhydrous state. The combinations of sulphuretted hydrogen, with salifiable bases, are sometimes termed hydro-sulphurets.

lents of the former to two of the latter. By exposure to the air it gradually loses weight, by throwing off one equivalent of its acid and its base, and becomes converted into the tasteless, inodorous bi-carbonate.

(§ 198.) To distinguish this constitution of a salt in the proportion of one and a half equivalent of acid to one of base (which is not a common occurrence) the term *sesqui* is prefixed to its name*.

(§ 199.) All the other acids named in the preceding table, form distinct and well-characterized salts, by combining in the proportion of their equivalents, and sometimes of their multiples, with ammonia; but they are not of importance enough to our object to require minute description.

CHAPTER VI.

On the Metals, the Oxides of which are reducible by mere Heat.

Mercury,	Rhodium,
Silver,	Iridium,
Gold,	Osmium,
Platinum,	Nickel,
	Palladium,

and their Binary Compounds.

(§ 200.) THE metallic elements, to which we are now about to direct our attention, form a highly interesting class; and are connected together by certain physical properties, which are common to them all.

They are opaque, and possess a lustre, even in their minutest fragments, so peculiar as to be well known to every one by the name of the *metallic lustre*. They are fusible at different degrees of heat, and when melted retain their opacity and brilliancy.

They reflect the greater part of the light and heat which falls upon their surface when polished, and form excellent mirrors. They are very good conductors both of electricity and heat. They belong to the class of electro-positive elements; passing, when subjected to the decomposing power of electricity, to the negative pole, from all their combinations with oxygen, chlorine, bromine, and iodine. They possess, in different degrees, a peculiar tenacity; which, when in its greatest perfection, renders them *malleable* and *ductile*, or capable of being extended under the hammer and drawn into wire.

The number of metals at present

recognised amounts to about forty, and for the purpose of facilitating the acquirement, retention, and application of a knowledge of their properties, it will be proper to divide them into different orders or groups.

With this view, a convenient, though by no means a perfect, arrangement may be formed upon the different force of their affinity for oxygen; which varies so greatly, that at one extremity of the scale the gaseous element is capable of being driven off by the mere application of heat; while at the other it is so strongly retained, as to require the utmost power of the voltaic pile to effect its separation. By classing them in this way, we shall have the incidental advantage of separating those which, generally speaking, have been longest known, and are most eminently endowed with the characters of the genus, and of most value for all the common purposes of life, from those which are the fruits of recent discoveries, and, in their metallic state, useless, except in the hands of the scientific experimentalist.

Our first division consists of those metals, whose oxides are reducible to the metallic state by the application of heat alone. These are nine in number, viz., Mercury, Silver, Gold, Platinum, Palladium, Rhodium, Iridium, Osmium, and Nickel. On account of their great inalterability, they have been popularly designated as *Noble Metals*. Their properties we shall proceed to investigate, and those of such of their binary compounds as are calculated to interest and instruct.

MERCURY.—200.

(§ 201.) MERCURY, or quicksilver, is the only metal which assumes the fluid form at the ordinary temperature of the atmosphere. When cooled to about 40° below 0° of Fahrenheit, a degree of cold which sometimes occurs naturally in very high polar latitudes, it becomes solid. It can also be congealed by artificial freezing mixtures, and the evaporation of sulphuret of carbon (§ 175) in the vacuum of an air-pump. In this state it is malleable, and may be cut with a knife. Its colour is white, but rather bluer than that of silver: its specific gravity at 47° above 0° is 13.6. It is volatile, and its vapour rises in small quantities, even at the common temperature of the air. At about 660° Fahrenheit it boils rapidly, and may be purified by distillation.

It is found in nature, in small quan-

* A Latin word, denoting the whole of a thing and one half more.

tities, in the metallic state; but the ore from which it is chiefly extracted is a sulphuret, commonly known by the name of *cinnabar*.

Its combining proportion, or equivalent number, is known from the analysis of its binary compounds, of which we shall proceed to give some account.

MERCURY AND OXYGEN.

Protoxide of Mercury.—208.

(1 M. 200 + 1 O. 8.)

(§ 202.) WE have already stated (§ 23), that when mercury is violently agitated, for a long time, in contact with atmospheric air, it combines with its oxygen, and becomes converted into a black, insipid, insoluble powder, which consists of 200 parts of metal and 8 of oxygen. This protoxide may more readily be obtained by triturating in a mortar calomel, with a solution of pure potash or hot lime-water. It must be washed with cold water, and gradually dried in a dark place, as with access of light and heat it rapidly resolves itself into the peroxide and metallic mercury.

This oxide, if exposed to the air at a moderate heat, absorbs a further proportion of oxygen; but if distilled in a glass retort its oxygen is evolved.

Per-oxide of Mercury.—216.

(1 M. 200 + 2 O. 16.)

(§ 203.) THE peroxide of mercury may not only be obtained by exposing the metal to the combined agency of heat and air, but also by dissolving it in nitric acid, and afterwards driving off the acid by a heat just sufficient for that purpose.

It is of a red colour, and sparingly soluble in water, to which it communicates the property of turning blue vegetable colours green. When distilled alone, in a glass tube, it yields oxygen gas, and the metal is revived. Careful analysis proves, that it contains just double the quantity of oxygen in the protoxide, or 8 parts in every 108.

Both the oxides of mercury combine with the acids, and constitute *salifiable bases*.

MERCURY AND CHLORINE.

Proto-chloride of Mercury.—236.

(1 M. 200 + 1 C. 36.)

(§ 204.) WHEN chlorine is brought into contact with mercury, at *common atmospheric temperatures*, the two substances combine in the proportion of one

equivalent of each: but the proto-chloride may more easily be obtained, by pouring into the solution of the metal in nitric acid a solution of common salt or muriatic acid. It is precipitated in the form of a ponderous, white powder, which must be washed and dried at a gentle heat. Proto-chloride of mercury, or calomel, has a specific gravity of 7.2; it is tasteless, and nearly insoluble in water. When exposed to heat, it sublimes unaltered: when scratched, it exhibits a yellow streak, which may distinguish it from other bodies. It constitutes a well-known and highly useful medicine.

Bi-chloride of Mercury.—272.

(1 M. 200 + 2 C. 72.)

(§ 205.) WHEN mercury is *heated* in chlorine, the two bodies combine together with a pale flame, in the proportion of one equivalent of the former and two of the latter. The bichloride, which is also well known by the name of *corrosive sublimate*, is prepared for medicinal purposes by intimately mixing together 73 parts of sulphate of mercury (formed by boiling together to dryness 50 parts of mercury with 70 of sulphuric acid) with 120 parts of common salt, and subliming. When thus obtained, it is of a crystalline texture, colourless, and semi-transparent. It is soluble in water, and highly poisonous. Its taste is acrid, burning, and metallic. Its specific gravity 5.2. It sublimes at a red heat, without change. If 272 parts, or one equivalent, of the bichloride be very intimately mixed, by trituration, with 200 parts, or one equivalent, of mercury, and the mixture sublimed, the proto-chloride will be obtained; and this is a common way of preparing calomel for use. When procured, however, by this process, it always contains a little corrosive sublimate; from which, after reducing it to powder, it should be carefully purified by washing.

MERCURY AND SULPHUR.

Proto-sulphuret of Mercury.—216.

(1 M. 200 + 1 S. 16.)

(§ 206.) BY long continued trituration together, mercury and sulphur combine in the proportion of one equivalent of each, and form a black-coloured powder. The same proto-sulphuret may also be obtained by transmitting a current of sulphuretted hydrogen through water, in which powdered calomel is kept sus-

pended. When exposed to heat, it is resolved into the bi-sulphuret and metallic mercury.

Bi-sulphuret of Mercury.—232.

(1 M. 200 + 2 S. 32.)

(§ 207.) WHEN mercury and sulphur are fused together, and afterwards sublimed, a red sulphuret is formed, which is known as a fine pigment by the names of *cinnabar* or *vermilion*. It contains exactly double the proportion of sulphur in the preceding sulphuret. It may also be prepared by pouring a solution of corrosive sublimate into a solution of hydro-sulphate of ammonia (§ 193). The precipitate which is obtained, is at first of a muddy-brown colour, but, when left undisturbed, gradually assumes the bright colour of *cinnabar*. It is from this compound, found in nature, that the mercury of commerce is procured. By mixing it with iron-filings and heating it, the sulphur passes to the iron, and the mercury is obtained by distillation.

SILVER.—110.

(§ 208.) SILVER is one of the metals which have been longest known to the inhabitants of the earth. It is of a beautiful white colour and great lustre. Its specific gravity is 10.5, and in malleability and ductility it exceeds all metals except gold. It may be extended into leaves, not exceeding $\frac{1}{100000}$ th of an inch in thickness, and drawn into wire finer than a human hair. Its fusing point, measured by Daniell's pyrometer, upon Fahrenheit's scale, is about 2233°. It may be volatilized by a very strong and long-continued heat. When cooled slowly, and the liquid part of the metal poured off, as soon as the surface has congealed, it may be obtained in crystals. Its uses for money and for ornamental articles of luxury are well known, for which purposes it is well adapted by its great inalterability; but it is always alloyed with other metals, and generally with copper. The tarnish which affects it arises from sulphureous vapours, not from oxidation.

It is found in silver mines, in the metallic state, and also in combination with other metals and with sulphur.

SILVER AND OXYGEN.

Oxide of Silver.—118.

(1 S. 110 + 1 O. 8.)

(§ 209.) SILVER may be obtained in

combination with oxygen by dissolving it in nitric acid, and mixing the solution with lime-water. After washing the precipitate with water, it should be dried at a temperature under redness. It is of an olive colour, insoluble in water, and tasteless. When heated to redness the oxygen is driven off, and the metal revived. It is composed of 110 parts of the metal and 8 of oxygen. It combines with the acids.

SILVER AND CHLORINE.

Chloride of Silver.—146.

(1 S. 110 + 1 C. 36.)

(§ 210.) SILVER combines with chlorine, and forms a compound well known by the name of *horn-silver*. It may be conveniently formed by adding a solution of silver in nitric acid to a solution of common salt. The white precipitate, which is the chloride of silver, becomes dark and finally black, if exposed to light, and especially to the direct rays of the sun. It is extremely insoluble in water, but readily taken up by ammonia. When heated to a dull red, in a silver crucible, it melts; and, on cooling, forms a semi-transparent substance not unlike horn. When fused with twice its weight of potash or soda it is decomposed, and a globule of pure silver obtained. A mixture of chloride of silver, chalk, and pearl-ash, is employed for silvering brass; such as thermometer-scales, clock-dials, &c. The metal is rendered very clean, and the mixture moistened with water well rubbed upon its surface. The results of the most careful analyses have proved it to be constituted of one equivalent of each of its ingredients.

SULPHUR AND SILVER.

Sulphuret of Silver.—126.

(1 S. 110 + 1 Su. 16.)

(§ 211.) WHEN thin plates of silver and sulphur are laid alternately above each other in a crucible, they combine together at a low red heat. The sulphuret is of a black colour, and capable of being cut with a knife. It is much more fusible than the metal. When strongly heated, the sulphur is slowly sublimed from it, and leaves the silver in purity. It is often found native in the mines. The same compound is also produced when sulphuretted hydrogen or hydro-sulphate of ammonia are

added to the solutions of the metal. It is a compound of 1 equivalent of the metal and 1 of sulphur.

SILVER AND MERCURY.

Amalgam of Silver.—310.

(1 S. 110 + 1 M. 200.)

(§ 212.) THE combinations of mercury with other metals are distinguished by the name of *amalgams*; some of them are definite compounds, and may be obtained in crystals, while others partake more of the nature of solutions. They are generally soft solids, of the consistency of butter.

Silver very readily combines with mercury; and a very sensible degree of heat is produced when silver-leaf and mercury are kneaded together in the hand. It is sometimes found native and crystallized; in which state its analysis has shown it to be composed of mercury 64, and silver 36—which is almost exactly in proportion of an equivalent of each. At a moderate heat the mercury evaporates and leaves the silver.

It is sometimes employed for an inferior kind of plating; for this purpose it is applied to the surface of copper, and the mercury being driven off by heat, the remaining silver is burnished.

GOLD.—200.

(§ 213.) GOLD, when pure, is of a yellow colour, and possesses a specific gravity of about 19.3. It exceeds all other metals in ductility and malleability. It may be beaten into leaves $\frac{1}{88000}$ th of an inch in thickness; and a wire of only $\frac{1}{17000}$ ths of an inch diameter will sustain a weight of 150lbs. Its melting point is about 2590° of Fahrenheit's scale. It is perfectly unchanged by fire with access of air, and the intense heat of a glass-house furnace has no other effect upon it than to keep it in fusion. It is not acted upon by any solvent, except a mixture of muriatic and nitric acids, or the *aqua regia* before described (§ 189). Its great value for the purposes of coin, when slightly alloyed with other metals, is well known. From its great beauty, inalterability, and lustre, it is also in the highest request for purposes of luxury and ornament. It has hitherto only been found in nature in the metallic state, either pure or in combination with other metals.

GOLD AND OXYGEN.

(§ 214.) MUCH uncertainty still exists with regard to the combinations of gold with oxygen. When a strong electric shock is passed through a fine gold wire or when in the state of thin leaf it is exposed to a strong current of electricity, from a voltaic battery, it is burnt, and a fine purple powder is the result, which there can be little doubt is an oxide of gold.

If gold be dissolved in a mixture of two measures of muriatic and one of nitric acids, the solution may be evaporated to dryness by a moderate heat, and the residual salt dissolved in water. A solution of pure potash may then be dropped into it, when, with the assistance of a moderate heat, a reddish yellow-coloured precipitate will be formed, which is also an oxide of the metal, combined with a portion of water. It may be rendered anhydrous by boiling, and it then assumes a brownish-black colour. It is insoluble in water, and it parts with its oxygen by exposure to solar light, or at a red heat. It is most probably a peroxide, and consists of one equivalent of gold 200, and 3 equivalents of oxygen 24, making its number 224. It is taken up by some of the acids.

GOLD AND CHLORINE.

(§ 215.) THE same degree of uncertainty exists with regard to the chlorides as to the oxides of gold. Gold leaf introduced into chlorine gas takes fire and burns; and if it be suspended in water, into which the gas is passed, it is dissolved, and the solution may be concentrated by evaporation. The solution obtained in the manner directed in the last section, consists also, most probably, of the same per chloride. By exposure to a moderate heat it parts with two-thirds of its chlorine, and is converted into a yellow insoluble protochloride.

GOLD AND SULPHUR.

Per-sulphuret of Gold.—248.

(1 G. 200 + 3 S. 48.)

(§ 216.) SULPHUR, even when assisted by heat, has no action on gold; but when a current of sulphuretted hydrogen is passed through a solution of that metal, a black precipitate is formed, which is a true sulphuret of gold. The sulphur may easily be expelled from this combination by heat. It is composed of

1 equivalent gold . . .	200
3 ditto sulphur . . .	48
	248

GOLD AND MERCURY.

Amalgam of Gold.

(§ 217.) MERCURY dissolves gold with great facility; and the amalgam is used, in the arts, for gilding. When applied upon the surface of the metals the mercury is driven off by heat, and a thin coating of gold remains: the process is called *water-gilding*. The amalgam may be obtained in crystals, in which case there can be no doubt that it is a definite compound.

PLATINUM.—96.

(§ 218.) PLATINUM, although only found in the metallic state, is comparatively but a late discovery. The general appearance of it in the rough state, in which it is brought to this country, is that of small grains or scales, darker than silver, and extremely heavy.

When purified it is of a white colour, lighter than that of iron, and exceeding all other metals in specific gravity: it being 21.5, and the most poudrous of all known substances. It is extremely difficult of fusion, but may be melted by a flame urged with oxygen gas. It possesses the valuable property of *welding*; that is to say, at a white heat an incipient fusion takes place, which covers its surface with a kind of varnish, so that, when brought into contact in this state, different pieces may be permanently united by forging. In this manner it can be hammered into bars, and afterwards beat out into plates or leaves for different purposes of art. Like gold, it is insoluble in any acid, except a mixture of the muriatic and nitric.

It has lately been found in Russia in considerable quantities, and employed for the purposes of coin, for which it is well adapted.

PLATINUM AND OXYGEN.

(§ 219.) CONSIDERABLE uncertainty exists with regard to the oxides of platinum. The metal cannot be made to combine with oxygen by the strongest heat of the best furnaces. When it has been dissolved in a mixture of muriatic and nitric acids, a precipitate may be formed by adding to the solution either soda or potash, which is said to be constituted of about 96 metal

and 16 oxygen. It is the basis of the salts of this metal.

PLATINUM AND CHLORINE.

(§ 220.) PLATINUM does not take fire when introduced in thin leaves into chlorine, but it slowly combines with the gas, and is converted into a chloride. The chloride is also formed by its solution in the nitro-muriatic acid. The solution should be evaporated to dryness, and then digested with muriatic acid, which should also be driven off. The dry mass may then be cautiously heated nearly to redness. Being boiled with a considerable quantity of water, and, finally, dried, the mass is most probably a chloride of platinum.

It is of an olive colour, and destitute of taste and smell. It is infusible, and scarcely soluble in water. When heated to redness, the chlorine is driven off, and the pure metal remains. It is composed of about

	Parts
Platinum . . .	96
Chlorine . . .	36
	132

PLATINUM AND SULPHUR.

(§ 221.) PLATINUM and sulphur combine together, directly, by mixing equal weights of the two in an exhausted glass tube, and heating them together. The mass should be finally heated nearly to redness, to expel every thing volatile. The sulphuret thus formed is of a dull bluish-grey colour. It has no lustre, but when rubbed on paper it leaves a metallic stain. Its analysis nearly corresponds with the assumption that it is a compound of one equivalent of each ingredient, or

Platinum . . .	96
Sulphur . . .	16
	112

PALLADIUM.—56.

(§ 222.) THE four following metals were all first found amongst the grains of rough platinum, imported into this country from South America, and their discovery soon followed the establishment of that metal as a distinct species. Palladium resembles platinum in colour, except that it is a little duller. It is malleable and ductile, and its specific gravity is about 11.5. Its point of fusion

appears to be intermediate between those of platinum and gold. In hardness, it is superior to wrought iron. On exposure to a strong heat it tarnishes a little, but it becomes bright again upon increasing the temperature. It is acted upon by the nitric, nitrous, sulphuric, and muriatic acids, but is most readily soluble in the nitro-muriatic.

PALLADIUM AND OXYGEN.

(§ 223.) PALLADIUM is thrown down from its solution by potash in the state of an oxide of an orange colour, which is supposed to be a compound of

1 equivalent palladium	. 56
1 ditto oxygen	. 8
	—
	64

and is the basis of its salts.

PALLADIUM AND SULPHUR.

Sulphuret of Palladium.—72.

(1 P. 56 + 1 S. 16.)

(§ 224.) ALTHOUGH palladium requires such a strong heat for its fusion, if touched when hot with a piece of sulphur, it runs like lead. The sulphuret is whiter than the metal, but very brittle. It is composed of

1 equivalent palladium	. 56
1 ditto sulphur	. 16
	—
	72
	—

RHODIUM.—44.?

(§ 225.) RHODIUM has only been procured in very minute quantities, from the solutions of crude platinum, in the form of a black powder, which requires the strongest heat of a wind furnace for its fusion. When fused, it has a white colour and metallic lustre: it is hard, brittle, and its specific gravity is about 11. It is not acted upon by any acid or mixture of acids, except when alloyed with other metals, in combination with which, it may be dissolved by the nitro-muriatic acid. Its solution, when freed from the metals with which it is mixed, is of a rose colour (from whence it derives its name); and pure potash precipitates from it a yellow oxide, which is soluble in all the acids which have been tried.

IRIDIUM AND OSMIUM.

(§ 226.) WHEN the crude platinum has been submitted to the action of nitro-muriatic acid, a part remains undissolved, in the form of a black powder, resem-

bling plumbago, which consists of a mixture of the metals iridium and osmium. By alternate and frequent digestions in soda and muriatic acid the two may be separated.

Iridium is white, and has only once been fused, by the power of an immense galvanic battery, into a porous metallic globule, which possessed the high specific gravity of 18.6. It may readily be alloyed with other metals, and gold retains its colour and malleability, though mixed with a considerable proportion. Its most marked character is its extremely difficult solubility in acids.

(§ 227.) Osmium can only be obtained as a metal in a disintegrated state; as it is capable of supporting a white heat, without being volatilized or fused. It is of a dark-grey or blue colour. If ignited in open vessels, with access of air, it is oxidized, and then dissipated in vapour. On agitating the metal with mercury, an amalgam is formed, and with copper, silver, and gold, it forms malleable alloys.

The pure oxide is soluble in water and volatile. It emits a peculiar odour, which has something of the pungency of chlorine, from whence it derives its name*. The aqueous solution is colourless; and, when shaken with mercury, is decomposed, soon loses its smell, and forms an amalgam.

NICKEL.—30.?

(§ 228.) THERE is a brittle reddish alloy, which is known in commerce by the name of *speiss*, which is chiefly a compound of nickel and arsenic; from which, by particular treatment, the former metal may be obtained in a state of purity. Its colour is white, and intermediate between those of silver and tin. When ignited, its colour changes to bronze. It will receive a very high polish, is very malleable, and may be forged, when hot, into bars; and when cold, may be hammered into plates, and drawn into fine wire. Its specific gravity is 8.5. It is attracted by the magnet, and is itself capable of having the magnetic power communicated to it. It is fusible with great difficulty. It suffers no change at common temperatures from either air or water; but by a long exposure to a red heat, with free access of air, it is converted into a brown oxide, which is still magnetic.

* From a Greek word, signifying odour,

NICKEL AND OXYGEN.

(§ 229.) THERE is, probably, more than one oxide of nickel; but some uncertainty exists with regard to their constitution. The metal burns vividly, and throws out sparks in oxygen gas. It may also be precipitated, in the state of oxide, from its solution in nitric acid by potash. The protoxide is calculated to be composed of

1 equivalent of nickel . .	30
1 ditto oxygen . .	8
	—
	38
	—

It is soluble in the acids, and also in ammonia, which latter property is made use of to separate it from iron. At a sufficiently high temperature all its oxides are reducible without addition.

CHAPTER VII.

On the Metals which absorb and retain Oxygen at high temperatures, but do not decompose water at any temperature.

Lead,	Uranium,
Tellurium,	Antimony,
Copper,	Columbium,
Bismuth,	Tungsten,
Titanium,	Chromium,
Cobalt,	Molybdenum,
Cerium,	Arsenic,

and their Binary compounds.

(§ 230.) The preceding division of the metals includes all those whose affinity for oxygen is so slight, that any connexion which they form with it is dissolved by the mere application of a high degree of temperature. We shall now proceed to examine those which absorb and retain oxygen at high temperatures, but whose affinity for that element is not sufficient to enable them to decompose water at any temperature. The list consists of fourteen, viz.—Lead, Tellurium, Copper, Bismuth, Titanium, Cobalt, Cerium, Uranium, Antimony, Columbium, Tungsten, Chromium, Molybdenum, and Arsenic.

LEAD.—104.

(§ 231.) LEAD is a common, useful, and well-known metal. When pure it has a bluish-white colour, and, when recently melted or cut, exhibits considerable lustre. It, however, very soon tarnishes. It is very soft and flexible. Its specific gravity is 11.3. It may be beaten into thin leaves, and drawn into wire. Its melting point is about 610° of Fahren-

heit. It is very rarely indeed met with in nature in the metallic state; but the ore from which it is chiefly derived is a sulphuret.

LEAD AND OXYGEN.

Protoxide of Lead.—112.

(1 L. 104 + 1 O. 8.)

(§ 232.) LEAD absorbs oxygen quickly at high temperatures; and, when fused in open vessels, a grey film forms upon its surface, which is a mixture of the metal and protoxide. By continuing the heat it assumes a uniform yellow colour. In this state the protoxide is called, in commerce, *massicot*; and, when partially melted, the term *litharge* is applied to it. When thus obtained, however, it is always impure.

When a solution of lead in nitric acid is precipitated by potash, the dried powder is the protoxide in a state of purity. It has a yellow colour; is insoluble in water; fuses at a red heat; but in close vessels is unchangeable in the fire. It has been carefully determined to be a compound of

1 equivalent of lead . .	104
1 ditto oxygen . .	8
	—
	112
	—

It constitutes the basis of the salts of lead.

Deutoxide of Lead.—232.

(2 L. 208 + 3 O. 24.)

(§ 233.) THE deutoxide of lead may be obtained by exposing the protoxide or *massicot* to heat, with a large surface and free access of air. It is then converted into the well-known pigment *red lead* or *minium*. At a red heat it gives off this second dose of oxygen, and returns to the state of protoxide. It may be regarded as a compound of

2 equivalents of lead . . .	208
3 ditto oxygen . .	24
	—
	232
	—

The simple proportions of which are

1 equivalent of lead . . .	104
1½ ditto oxygen . .	12
	—
	116
	—

in which view the multiple of the oxygen of the first oxide, not being an entire number, would form an exception to the general law of chemical composition.

Peroxide of Lead.—120.

(1 L. 104 + 2 O. 16.)

(§ 234.) WHEN the deutoxide of lead is digested with nitric acid, the greater part is reduced to the state of protoxide, and dissolved; but a dark brown powder remains insoluble, which is the peroxide. It is composed of

1 equivalent of lead	. .	104
2 ditto oxygen	. .	16
		120

When strongly heated it gives off three or four per cent. of oxygen gas, and is converted into protoxide. By passing a stream of chlorine through red lead diffused in water, a solution is obtained, from which this peroxide may be precipitated, in abundance, by potash.

(§ 235.) The oxides of lead are easily vitrified, and have the property of combining with all the metals except gold, silver, and platinum, and those which are found peculiarly associated with the latter. Gold and silver may thus be purified by melting them with lead: the process is called *cupellation*. The metal to be purified is wrapped up in a sheet of lead, and laid upon a crucible made of some very porous substance: they melt together, the lead becomes first oxidated, then vitrified, and sinks into the *cupel*, carrying along with it all the baser metals, and leaving the gold or silver upon its surface.

LEAD AND CHLORINE.

Chloride of Lead.—140.

(1 L. 104 + 1 C. 36.)

(§ 236.) WHEN lead, in filings, is thrown into chlorine moderately warmed, the metal burns with a white flame, and throws off sparks. The combination, however, may more readily be produced for examination by adding some common salt to a solution of lead in nitric acid. The precipitate must be well washed in water, and dried.

The chloride of lead has a sweet taste, and is soluble in twenty-two parts of water at common temperatures. It is fusible at a heat below redness, and then assumes the appearance and consistence of horn, and has been called *horn lead*. It may also be volatilized by raising the heat. It is composed of

1 equivalent of lead	. .	104
1 ditto chlorine	. .	36
		140

LEAD AND SULPHUR.

Sulphuret of Lead.—120.

(1 L. 104 + 1 S. 16.)

(§ 237.) LEAD readily combines with sulphur, and forms a compound less fusible than the metal, and of a metallic lustre. It is found in nature; and, under the name of Galena, constitutes the most abundant ore from whence the metal is derived. The sulphuret consists of

1 equivalent of lead	. .	104
1 ditto sulphur	. .	16
		120

TELLURIUM.—29.?

(§ 238.) TELLURIUM is a metal of small importance, found only in minute quantities in the gold mines of Transylvania. Its colour is between those of tin and lead: it has considerable lustre, and its fracture is scaly. It is very brittle, and melts at a temperature below ignition. It is the most volatile of all the metals except mercury, and may readily be distilled. Its vapour condenses into brilliant metallic drops. Its specific gravity is only 6.1.

TELLURIUM AND OXYGEN.

(§ 239.) TELLURIUM is oxidized when heated in contact with air, and burns with a sky-blue flame, edged with green. It gives off a grey smoke, of a pungent nauseous smell, which condenses into a white oxide. It is fusible and volatile at high temperatures. There are some doubts with regard to its analysis, but it is probably a compound of

1 equivalent of tellurium	. .	29
1 ditto oxygen	. .	8
		37

It combines both with acids and alkalies and other bases.

TELLURIUM AND HYDROGEN.

Telluretted Hydrogen Gas.

(§ 240.) TELLURIUM possesses the singular property of combining with hydrogen. The compound may be obtained by mixing together oxide of tellurium, hydrate of potash, and charcoal, at a red heat, and acting upon the mixture by dilute sulphuric acid. The product is gaseous, and must be received over mercury.

Telluretted hydrogen gas is soluble in

water, and forms a claret-coloured solution. It burns with a bluish flame, and deposits the oxide of the metal. Its smell is peculiar, but not unlike that of sulphuretted hydrogen. Like that compound it reddens litmus paper, and may be considered as a feeble acid.

COPPER.—64.

(§ 241.) WE are now arrived at the consideration of a metal as important to the service of man as the last has hitherto proved insignificant. The physical properties of copper are known to every one. It possesses a beautiful red colour, and considerable lustre. It has a peculiar smell when warmed or rubbed. Its specific gravity is about 8.8. It may be hammered into very thin leaves, and drawn into wire. Its melting point is very little below that of gold, being about 2548° of Fahrenheit's scale. By a more violent heat, it may be made to boil, and to evaporate in visible fumes. It is found in the metallic state in nature, but the great source of its supply is an ore in which the metal is found combined with sulphur.

COPPER AND OXYGEN.

Protoxide of Copper.—72.

(1 C. 64 + 1 O. 8.)

(§ 242.) COPPER tarnishes and rusts in the air by combining with its oxygen. The protoxide may be obtained by heating together to redness, in a close vessel, sixty-four parts of metallic copper with eighty parts of the peroxide, which we shall presently describe. When a plate of copper is exposed for some time to heat in contact with air, and afterwards hammered, it throws off scales, which are a mixture of metallic copper and peroxide; and, when treated as above directed, will also afford the protoxide.

It is of a red colour, and is composed of

1 equivalent of copper	. . .	64
1 ditto oxygen	. . .	8
		72

It is often found native in beautiful red crystals.

It is dissolved by some of the acids, and also by ammonia.

Peroxide of Copper.—80.

(1 C. 64 + 2 O. 16.)

(§ 243.) THE peroxide of copper is easily

obtained pure by keeping the scales above described at a red heat exposed to air. It may also be procured by dissolving the metal in nitric acid, and adding potash; when an abundant precipitate will be formed, which must be sufficiently heated to drive off any water which it may contain. This oxide is a tasteless black powder, and is composed of

1 equivalent of copper	. . .	64
2 ditto oxygen	. . .	16
		80

It forms salts with the acids, and is also soluble in ammonia.

COPPER AND CHLORINE.

Protochloride of Copper.—100.

(1 C. 64 + Ch. 36.)

(§ 244.) WHEN copper filings are introduced into chlorine they take fire, and two compounds of the elements are produced. One of these is the protochloride. It is a fixed yellowish substance, slightly transparent, not unlike rosin, and easily fused. It may be conveniently made by heating together two parts of the perchloride of mercury, and one of copper filings. It is insoluble in water. Muriatic acid dissolves it without effervescence, and water precipitates it unchanged. When heated to redness in close vessels, it remains fixed and unchanged, but in the open air it is dissipated with white fumes. It is composed of

1 equivalent of copper	. . .	64
1 ditto of chlorine	. . .	36
		100

Perchloride of Copper.—136.

(1 C. 64 + 2 Ch. 72.)

(§ 245.) THE perchloride of copper is formed by the action of chlorine upon copper, at the same time as the protochloride. It sublimes in the state of a yellowish-brown powder. When exposed to the air, it absorbs moisture, and becomes first white, and then green. It is decomposed by heat, which converts it into protochloride, by driving off one proportion of chlorine. It is constituted of

1 equivalent of copper	. . .	64
2 ditto chlorine	. . .	72
		136

COPPER AND SULPHUR.

(§ 246.) The protosulphuret, and the persulphuret of copper, have been already described (§§ 21 and 22) for the purposes of illustration. It is unnecessary to add anything here to the description which we have given.

BISMUTH.—71.

(§ 247.) BISMUTH is a metal of a reddish white colour, whose fracture shows it to be composed of brilliant plates adhering together. Its specific gravity is 9.8. It is scarcely malleable, breaks under the hammer, and cannot be drawn into wire. It is very fusible, and melts at a temperature of 476° of Fahrenheit. It may be obtained in fine crystals by slow cooling, and may be completely volatilized at a high heat out of contact with the air. When melted in the air its surface becomes covered with a greenish-brown oxide.

BISMUTH AND OXYGEN.

Oxide of Bismuth.—79.

(1 B. 71 + 1 O. 8.)

(§ 248.) BISMUTH takes fire, and burns with a blue flame, when strongly heated with access of air, forming an oxide of a yellowish colour, known by the name of *flowers of Bismuth*. It is very fusible, and, like the oxides of lead, is converted by heat into glass. It has sometimes been employed for the purposes of cupellation (§ 235). It is constituted of

1 equivalent bismuth . . .	71
1 ditto oxygen . . .	8
	79

It forms salts with the acids.

BISMUTH AND CHLORINE.

Chloride of Bismuth.—107.

(1 B. 71 + 1 C. 36.)

(§ 249.) BISMUTH, in a state of fine division, takes fire in chlorine, burns with a pale blue light, and is converted into a chloride. It is of a greyish-white colour, granular texture, and opaque. It is not sublimed by heat. Its analysis proves it to be composed of

1 equivalent of bismuth . . .	71
1 ditto chlorine . . .	36
	107

ALLOYS OF BISMUTH.

(§ 250.) BISMUTH is capable of being alloyed with most metals, and forms,

with some of them, compounds of remarkable fusibility. On this account it is much used for the composition of *soft solders*. A mixture of 8 parts of bismuth, 5 of lead, and 3 of tin, forms an alloy, which melts below the temperature at which water boils, and is known by the name of *fusible metal*.

TITANIUM.

(§ 251.) TITANIUM has only, till very recently, been found in small quantities in the state of an oxide, in a few rare minerals. It has probably never, but once, been completely reduced by art to the metallic state, the process being very difficult, and requiring a very high heat. It is described as of a dark copper colour, with much brilliancy, brittle, and, in small scales, possessing considerable elasticity. Very lately, the metal has been found in minute cubic crystals, in the slags taken from the bottom of the smelting furnaces of large iron-works. Their colour and lustre is like burnished copper; their specific gravity 5.3: and they are so hard, that they scratch a polished surface of rock-crystal. The metal is exceedingly infusible. It tarnishes in the air, and is easily oxidized by heat. Too little is known regarding this untractable substance to enable us to fix its equivalent.

TITANIUM AND OXYGEN.

(§ 252.) TITANIUM is probably susceptible of three degrees of oxidation: the first oxide is blue, the second red, and the third white. The red oxide is found in nature in prismatic crystals; the white is the basis of its salts.

COBALT.

(§ 253.) COBALT is a brittle, somewhat soft, but difficultly fusible metal. Its colour is reddish-grey; it possesses little lustre; and its specific gravity is 8.6. It is attracted by the magnet, and is capable of becoming magnetic. It tarnishes by exposure to air. Its equivalent has not been fixed with certainty, owing to some discrepancy in the analysis of its compounds.

COBALT AND OXYGEN.

(§ 254.) IN a very intense heat, cobalt burns with a red flame.

An oxide may be formed by long exposure to a strong heat, with access of air: it is of a deep blue, approaching to black. It is probably a protoxide; and may also be formed by precipitating

the solution of the metal in nitric acid by potash. The precipitate is at first combined with water, and of a bright blue colour, but by drying assumes so dark a blue as to appear black.

When this oxide is exposed to the air it gradually absorbs a further dose of oxygen, and is converted into an olive green.

Both these oxides, by being heated in the air, pass to the state of peroxide, and become of a brown colour. The fine blue substance, known in commerce by the name of *zaffre*, is oxide of cobalt fused with sand or calcined flints. This, when finely ground and washed, is called *smalts*, and is much used for imparting a blue colour to linen, and for staining glass and china. All the salts of cobalt contain the protoxide.

CERIUM.

(§ 255.) THE only minerals which are known to contain the metal cerium are extremely rare, even in the cabinets of collectors; and the attempts to reduce the oxide to the metallic state have either failed or merely produced a small globule not larger than a pin's head. This metallic globule was harder, whiter, much more brittle, and more scaly in its fracture than cast iron.

It appears that there are two oxides of the metal: the protoxide is white, and the peroxide of a reddish colour. Both the oxides form salts with the acids.

URANIUM.

(§ 256.) The ores of this metal are scarcely less rare than those of the preceding, and are nearly as difficult of reduction. It has, however, been obtained in the form of a metallic button, of the weight of 28 grains; of a dark grey colour, hard, and firmly cohering. On filing it, or rubbing it with another hard body, it exhibited a metallic lustre of an iron-grey colour. Its specific gravity has been found as high as 9.

There are, probably, two oxides of the metal: the protoxide, which is greyish-black; and the peroxide, which is yellow.

The two oxides are employed in the arts; the first to give a black, the second, an orange colour, to porcelain.

ANTIMONY.—44.

(§ 257.) Antimony, in its metallic state, is of a dusky-white colour, very brittle, and of a scaly texture. Its

specific gravity is about 6.8. It melts at a heat of about 810° Fahrenheit, and crystallizes on cooling. Its surface tarnishes by exposure to the atmosphere, and when heated to whiteness, in a covered crucible, and suddenly exposed to the air, it burns with a white light. It is obtained for use from the native sulphuret.

ANTIMONY AND OXYGEN.

Protoxide of Antimony.—52.

(1 A. 44 + 1 O. 8.)

(§ 258.) IF to a solution of the well-known medicine called *tartar emetic*, we add a solution of pure ammonia, a protoxide of antimony will be precipitated, which should be washed with plenty of hot water. It is of a dirty-white colour, fuses at a red heat, and forms on cooling an opaque crystalline mass. It may be sublimed in close vessels by a strong heat. When exposed in open vessels, to a red heat, it absorbs a further dose of oxygen, and is converted into the deutoxide. It is composed of

1 equivalent of antimony .	44
1 ditto oxygen .	8
	—
	52

It forms salts by combination with the acids.

Deutoxide of Antimony, or Antimonious Acid.—56.

(1 A. 44 + 1½ O. 12.)

(§ 259.) WHEN antimony, or its protoxide, is strongly heated in open vessels, or when the metal is burnt in oxygen, the deutoxide is formed. It sublimes, and may be condensed on a cold surface in the form of needles of a silvery whiteness. It does not readily fuse, and is more volatile than the protoxide. It is quite insoluble in water, but possesses many of the properties of an acid, and enters into combination rather with alkalies than with acids. It is composed of

1 equivalent of antimony .	44
1½ ditto oxygen .	12
	—
	56

(§ 260.) THE composition of the deutoxide of antimony presents, when thus regarded, an exception to the general law of chemical composition, which

also occurs in two or three other metals, viz., that the multiple of the oxygen of the first oxide is $1\frac{1}{2}$, and not an entire number. The theoretical difficulty, however, may be removed by considering (as we have already done in the similar instance of lead, § 233) this oxide as composed of two equivalents of the metal and three of oxygen (2 A. 88 + 3 O. 24), or as a compound of one equivalent of the protoxide with one of the following or peroxide (52 + 60).

Peroxide of Antimony, or Antimonic Acid.—60.

(1 A. 44 + 2 O. 16.)

(§ 261.) THE peroxide of antimony may be obtained, by dissolving the metal in nitromuriatic acid; from which it may be precipitated by throwing the solution into water, as it is insoluble in that fluid. When recently prepared it reddens litmus paper. It is thus obtained in the form of a white *hydrate*; but if exposed to a temperature not exceeding 600° Fahrenheit, the water is driven off, and pure peroxide remains, of a yellow colour. When exposed to a red heat it parts with a portion of its oxygen, and is converted into the deutoxide. It enters into definite combinations with alkalis, and not with acids, and hence it ranks with the latter class of bodies.

ANTIMONY AND CHLORINE.

Protochloride of Antimony.—80.

(1 A. 44 + 1 C. 36.)

(§ 262.) WHEN powdered antimony is thrown into chlorine, combustion ensues, and the protochloride is formed by the union of the two. It may also be produced by distilling a mixture of antimony with twice and a half its weight of bichloride of mercury. The chloride of antimony being very volatile, passes over into the receiver, and metallic mercury remains in the retort. At common temperatures it is a soft solid, which liquifies at a gentle heat, and was formerly called butter of antimony. It deliquesces on exposure to the air.

Bichloride of Antimony.—116.

(1 A. 44 + 2 C. 72.)

(§ 263.) BY passing dry chlorine gas over heated metallic antimony, a transparent volatile fluid is obtained, which emits fumes on exposure to the air. It contains twice as much chlorine as the protochloride,

ANTIMONY AND SULPHUR.

Sulphuret of Antimony.—60.

(1 A. 44 + 1 S. 16.)

(§ 264.) ANTIMONY readily combines with sulphur, and forms a grey sulphuret with metallic lustre. The same compound is found in nature. It may be melted in close vessels without undergoing any change; but, when slowly roasted in a shallow vessel, it gradually loses sulphur and attracts oxygen, and may then be melted into a glassy substance, transparent at the edges, and called *glass of antimony*. It consists of eight parts of protoxide, and one of sulphuret.

ALLOYS OF ANTIMONY.

(§ 265.) ANTIMONY may be made to combine with most of the metals. A very slight admixture of it, not exceeding $\frac{1}{1000}$ th of the mass, is sufficient to destroy the ductility of gold, and even its fumes alone will produce that effect. When mixed with lead, in the proportion of one part in seventeen, it composes the metal for printers' types.

COLUMBIUM.—144.

(§ 266.) THIS and the succeeding species furnish further instances of highly refractory metals extracted with great difficulty from very rare minerals, whose discovery and examination have afforded exercise for the highest talents, but which have not hitherto been applied to any use in the arts.

The colour of columbium is iron-grey, and, when scratched with a knife, it shows the metallic lustre. It has only been obtained in agglutinated particles by an intense heat, the specific gravity of which was 5.6. It is not acted upon by nitric or muriatic acids, or by a mixture of the two.

COLUMBIUM AND OXYGEN.

Oxide of Columbium, or Columbic Acid.—162.

(1 C. 144 + 1 O. 8.)

(§ 267.) THE only oxide of columbium known possesses the properties of an acid, and forms definite compounds with alkalis rather than with acids. It is found in nature in combination with oxide of iron. When purified, it is of a white colour, and, when laid upon wet litmus paper, it converts the blue colour to a red. It is tasteless, and insoluble in water. It does not acquire any

colour by exposure to a high temperature with access of air. It is believed to be a compound of

1 equivalent of columbium .	144
ditto oxygen . . .	8
	—
	152
	—

Its specific gravity is 6.5.

TUNGSTEN.—96.

(§ 268.) TUNGSTEN has a greyish-white colour, like that of iron, but is not magnetic. Its specific gravity is 17.2. It is extremely hard and brittle, and fusible with great difficulty. It is oxidized by the action of heat and air.

TUNGSTEN AND OXYGEN.

Protoxide of Tungsten.—112.

(1 T. 96 + 2 O. 16.)

(§ 269.) WHEN hydrogen gas is passed over tungstic acid (which will be immediately described) at a red heat, it is converted into a dark-brown oxide, in which the oxygen is to that in the acid as 2 to 3. When heated in the air it burns like tinder, and is reconverted into the acid.

Tungstic Acid.—120.

(1 T. 96 + 3 O. 24.)

(§ 270.) TUNGSTIC acid is a compound of three equivalents of oxygen and one of tungsten. It is of a yellow colour, insoluble in water, and has no effect upon the blue colour of litmus. It forms definite compounds with the alkalies. Its specific gravity is 6.1.

CHROMIUM.—28.

(§ 271.) CHROMIUM is a rare metal, and is extracted from only two minerals; in one of which it is combined, as an acid, with lead, and in the other, as an oxide, with iron. It requires a violent heat for its reduction. It has merely been obtained as a porous mass of agglutinated grains. It is very brittle, of a greyish-white, intermediate between tin and steel. Its specific gravity is 5.9.

CHROMIUM AND OXYGEN.

Protoxide of Chromium.—36.

(1 C. 28 + 1 O. 8.)

(§ 272.) IT is probable that chromium forms two oxides by union with oxygen, besides the acid which will be presently described. The protoxide may be ob-

tained by heating a salt called chromate of mercury to redness. The mercury is thus dissipated in vapour, and at the same time the chromic acid is resolved into oxygen and the protoxide of chromium. It is of a green colour; insoluble in water; infusible; and suffers no change from the exposure to heat. It is probably a compound of

1 equivalent of chromium . .	28
1 ditto oxygen . . .	8
	—
	36
	—

It is soluble in the acids. It is employed in the arts to give a beautiful green colour to porcelain, and is the colouring principle of the emerald.

Deutoxide of Chromium.—44.

(1 C. 28 + 2 O. 16.)

(§ 273.) THE deutoxide is of a brown colour, and may be formed by exposing a solution of the protoxide in nitric acid to a heat just sufficient to decompose the acid. Very little is known concerning it. It does not enter into combination with the acids.

Chromic Acid.—52.

(1 C. 28 + 3 O. 24.)

(§ 274.) THE chromic acid is found in nature in combination with lead, and may be extracted by boiling the powdered mineral with twice its weight of carbonate of potash, and afterwards saturating the alkali by a mineral acid. It is of a red colour, and may be obtained, from its solution, in ruby-coloured crystals. It has a sour metallic taste. When exposed to heat it gives off oxygen, and is converted into the protoxide. It is probably constituted of

1 equivalent of chromium . .	28
3 ditto oxygen . . .	24
	—
	52
	—

It gives its colour to the ruby.

MOLYBDENUM.—48.

(§ 275.) MOLYBDENUM has never been reduced into masses of any considerable magnitude, but has only been obtained in small globules, in a blackish brilliant mass. It is grey, brittle, and very infusible. Its specific gravity is 8.6. It is found in nature in the state of sulphuret, and united as an acid with lead. Both are very rare minerals.

MOLYBDENUM AND OXYGEN.

Molybdous Acid.—64.

(1 M. 48 + 2 O. 16.)

(§ 276.) THE molybdous acid may be formed by triturating together one part of molybdenum with two parts of molybdic acid, presently to be described, with a little hot water. By evaporating the solution thus formed, at a temperature not exceeding 120° Fah., the acid is obtained in the form of a fine blue powder. It reddens vegetable blues, and combines with alkaline bases. It consists of about 100 metal and 34 parts oxygen.

Molybdic Acid.—72.

(1 M. 48 + 3 O. 24.)

(§ 277.) THE native sulphuret of molybdenum, being roasted for some time, may be reduced to fine powder, and dissolved in liquid ammonia. When nitric acid is added to the solution, the molybdic acid is precipitated in white scales, which become yellow upon melting or subliming them. It changes the vegetable blues to red, and has a sharp metallic taste. It is sparingly soluble in water; and paper dipped in the solution, becomes, when dried in the sun, of a beautiful blue. When the metal is heated with access of air, it absorbs oxygen, and is converted into the acid.

ARSENIC.—38.?

(§ 278.) THE substance commonly met with under the name of arsenic is an oxide, from which the metal may be obtained by mixing it with oil, and subliming at a low red heat in a clean Florence flask. The arsenic will thus be reduced, and will be found lining the neck of the flask in a state of metallic brilliancy, not unlike polished steel. It is very brittle, and may be reduced to powder by pounding in a mortar. Its specific gravity is 8.3. It is readily fusible and volatilized. It may be collected, unchanged, in close vessels; but if thrown on red hot iron, it burns with a blue flame and white smoke; it emits also a strong smell of garlic, which belongs to it in its metallic state, and not to its oxides. Arsenic is speedily tarnished by exposure to air, and converted into a black powder, which is a mixture of the metal and oxide.

ARSENIC AND OXYGEN.

Arsenious Acid.—54.

(1 A. 38 + 2 O. 16.)

(§ 279.) ARSENIUS acid, or white oxide

of arsenic, is white, semi-transparent, and brittle. It has a faintly-sweet taste, and is well-known to be highly poisonous. It is volatilized at a temperature of 380° Fah.; but, if suddenly heated may be melted into a kind of glass. It is sparingly soluble in water, and more so in hot than in cold. It reddens vegetable blue colours. There is some uncertainty with regard to the analysis of this compound, and indeed with regard to the other combinations of arsenic, so that its equivalent cannot be said to be absolutely determined. It is probably constituted of

1 equivalent of arsenic	-	38
2 ditto oxygen	-	16
		—
		54

Arsenic Acid.—62.

(1 A. 38 + 3 O. 24.)

(§ 280.) ANOTHER compound of arsenic and oxygen may be formed by boiling one part of arsenious acid to dryness in six parts of nitric acid. Nitric oxide is given off, and a white, concrete substance remains, which is the arsenic acid. It has a sour, metallic taste; reddens vegetable blues, and attracts moisture from the air. When its solution is evaporated it assumes the consistence of jelly, but does not crystallize. It is a very active poison. It may be melted into a glass which is deliquescent; and, at a very strong red heat, it is converted into arsenious acid and oxygen. It is probably composed of

1 equivalent of arsenic	-	38
3 ditto oxygen	-	24
		—
		62
		—

ARSENIC AND HYDROGEN. :

Arseniuretted Hydrogen.

(§ 281.) ARSENIC combines with hydrogen, and forms a very poisonous compound; to his researches on which, one eminent chemist owed his death. It may be formed by melting together, in a covered crucible, three parts of granulated tin and one part of metallic arsenic in powder, and submitting the alloy, in fragments, to the action of muriatic acid in a glass retort. On the application of a moderate heat a gas is given off, which may be collected over the water bath. It is colourless, without acid properties, and its specific gravity is about 0.5. It extinguishes combustible bodies,

but burns with a blue flame. Its smell resembles that of garlic, but is more fetid. It instantly destroys small animals which are immersed in it. Its composition has not been accurately determined, but it is believed that the hydrogen exists in it in a condensed state; for it deposits arsenic, and is expanded in volume at high temperatures.

ARSENIC AND SULPHUR.

(§ 282.) ARSENIC combines with sulphur in two proportions, and both the sulphurets are found native. The compound with the least proportion of sulphur is red, and known in commerce by the name of *realgar*; that with the greatest proportion is of a bright yellow, and is named *orpiment*. The sulphur exists in the two in the proportion of 2 to 3. They have both been employed in calico-printing and dyeing.

CHAPTER VIII.

On the Metals which absorb and retain Oxygen at high temperatures, and decompose Water at a red heat.

*Tin, Iron, Zinc,
Cadmium, Manganese,
and their Binary Compounds.*

(§ 283.) PURSUING the plan which we have laid down, we come now to a class of metals whose affinity for oxygen is such that they not only absorb oxygen from the atmosphere, and retain it at a high temperature, but abstract it also from water, when assisted by a heat not below redness. This list consists only of five—Tin, Iron, Zinc, Cadmium, and Manganese.

TIN.—59.

(§ 284.) TIN is a well-known metal; but the substance which is popularly so called consists of sheets of iron merely plated with it. It is a silvery-white metal, which, by exposure to the air, acquires a slight, superficial tarnish. It is very soft; and, when bent backwards and forwards, occasions a peculiar crackling noise. It is very malleable, and its specific gravity is about 7.9. It melts at a temperature of 442° Fah. It is chiefly found, in nature, in the state of oxide, which constitutes the ore from which it is obtained for commerce.

TIN AND OXYGEN.

Protoxide of Tin.—67.

(T. 59 + 1 O. 8.)

(§ 285.) WHEN tin is kept for a long

time melted in contact with the air, it absorbs oxygen, and is converted into a grey powder. This protoxide may also be obtained by pouring nitric acid, diluted with ten times its bulk of water, upon tin filings, and leaving them in contact forty-eight hours. It should be carefully dried without being exposed to the air. This oxide has such a strong affinity for a further dose of oxygen, that, when heated to redness in open vessels, it is converted into peroxide with evolution of heat and light. It will be hereafter seen that it carries this avidity for oxygen with it into most of its combinations. It is composed of

1 equivalent of tin	- - -	59
1 ditto oxygen	-	8
		67

This oxide is soluble in the acids and in ammonia; and the ammoniacal solution, when long kept, deposits metallic tin in crystals, and becomes a solution of peroxide.

Peroxide of Tin.—75.

(1 T. 59 + 2 O. 16.)

(§ 286.) THE peroxide may be obtained either by heating the protoxide, as we have just stated, or by the action of nitric acid, slightly diluted, upon the metal. A white powder is produced, which is a hydrate of the peroxide, from which the water may be expelled by a red heat. The peroxide of tin is of a straw-yellow colour. It is insoluble in all the acids, except the muriatic, but unites feebly with the alkaline bases. It is constituted of

1 equivalent of tin	- - -	59
2 ditto oxygen	-	16
		75

TIN AND CHLORINE.

Protochloride of Tin.—95.

(1 T. 59 + 1 C. 36.)

(§ 287.) THE protochloride of tin may be formed by heating together an amalgam of tin and mercury with the protochloride of mercury (calomel). It is a grey, semi-transparent, crystalline solid. It is soluble in water, and forms a solution which rapidly attracts oxygen from the air, and deposits peroxide of tin. Its analysis shows it to be composed of

1 equivalent of tin	- - -	59
1 ditto chlorine	-	36
		95

Perchloride of Tin.—131.

(1 T. 59+2 C. 72.)

(§ 288.) TIN, in a state of fine division, may be burnt in chlorine; when a volatile, clear liquid is formed. This perchloride may also be produced by heating together tin filings and perchloride of mercury. It has the property of inflaming oil of turpentine when suddenly poured into that fluid. It emits white fumes when exposed to the air, from its great attraction for its moisture. When mixed with a little water, it is converted into a solid crystalline substance. It is composed of

1 equivalent of tin - -	59
2 ditto chlorine -	72
	131

TIN AND SULPHUR.

(§ 289.) THERE are two sulphurets of tin. The proto-sulphuret may be formed by fusing together tin and sulphur. It is of a bluish colour, lamellated texture, and brittle. It is composed of one equivalent of each of its ingredients. The bi-sulphuret may be made by heating together, in close vessels, the peroxide of tin and sulphur. It is produced in fine flakes of a beautiful gold colour, and was formerly known by the name of *Mosaic gold*. It is composed of

1 equivalent of tin - -	59
2 ditto sulphur -	32
	91

It is used as a pigment for giving a gold colour to some works of art.

ALLOYS OF TIN.

(§ 290.) THE alloys of tin with copper in various proportions, form *bronze*, *bell-metal*, or *gun-metal*: and, when the proportion of the first is about one-third, the alloy is beautifully white, and used for the reflectors of telescopes.

IRON.—28.

(§ 291.) IRON is at once the most diffused, the most abundant, and the most important of the metals. It is found in all the three kingdoms of nature: its ores constitute almost mountains; and there is scarcely an art which could exist, in any perfection, without it. It has a bluish-white colour, and is susceptible of a very high polish. It is very malleable, and is capable of being

drawn into very fine wire, though not of being beaten into very thin leaves. Its specific gravity is about 7.7. It is one of the most infusible of the metals; but this disadvantage is counterbalanced, for all practical purposes, by its possessing the property of welding (§ 218) in high perfection. Cast iron, or iron in that state in which it is first run from its ores, and which is very far from pure, has been found to melt at a temperature equal to about 3479° of Fahrenheit's scale; but the fusing point of the pure metal is, doubtless, higher. At common temperatures it is exceedingly hard; but, when heated to redness, very soft and ductile. It is attracted by the magnet, and capable of having the magnetic virtue imparted to it. It is, very rarely, found native in the metallic state; in masses which are, with great probability, supposed to be of meteoric origin. The ores from which its supply is chiefly derived are oxides of the metal.

IRON AND OXYGEN.

Protoxide of Iron.—36.

(1 I. 28 + 1 O. 8.)

(§ 292.) THE affinity of iron for oxygen is very great. We have already seen that it may be burned in oxygen gas (§ 39); and, when heated to redness in the open air, it absorbs oxygen rapidly, and is converted into black scales, called the *black oxide* of iron. This is, however, not a definite compound, but a mixture of protoxide and peroxide. The same compound is also produced when the steam of water is brought into contact with red hot iron (§ 47).

The protoxide of iron may be obtained pure by passing dry hydrogen gas over the peroxide at a temperature a little below redness. Its colour is a very dark blue. It is attracted by the magnet, but not so strongly as the metal itself. It is very combustible; and, when thoroughly exposed to the air at common temperatures, it spontaneously ignites, and becomes converted into the peroxide. All its combinations are also characterised by this high attraction for oxygen. It is composed of

1 equivalent of iron - -	28
1 ditto oxygen -	8
	36

Peroxide of Iron.—40.

(1 I. 28 + 1½ O. 12.)

(§ 293.) WHEN iron is dissolved in

nitric acid, then boiled for some time, precipitated by ammonia, and exposed to a low red heat, it is converted into peroxide. It is of a red colour, and not attracted by the magnet. It is composed of

1 equivalent of iron	-	-	28
$1\frac{1}{2}$ ditto oxygen	-	12	—
			40

and presents another instance of the anomaly to which we have before referred (§ 260), namely, that the oxygen of the peroxide is not a multiple, by a whole number, of that of the protoxide. Both the oxides of iron constitute salifiable bases.

IRON AND CHLORINE.—64.

Proto-chloride of Iron.

(1 I. 28 + 1 C. 36.)

(§ 294.) WHEN iron is dissolved in diluted muriatic acid, a green solution is obtained, which should be evaporated to dryness, and ignited out of the contact of the air. The product has a grey colour, a metallic splendour, and a lamellar texture. This proto-chloride is a fixed substance, and requires a red heat for its fusion. There are some doubts attending the results of its analysis.

Perchloride of Iron.—82.

(1 I. 28 + $1\frac{1}{2}$ C. 54.)

(§ 295.) WHEN iron wire is burned in chlorine, a bright yellowish-brown substance is obtained, of a high degree of lustre, which is volatile at a temperature a little above 212° Fah., and crystallizes in the form of small iridescent plates. It is composed of

1 equivalent of iron	-	-	28
$1\frac{1}{2}$ ditto chlorine	-	54	—
			82

and exhibits the same anomaly of the half-equivalent as the peroxide. They may each be considered, in a theoretical point of view as before suggested (§ 260), as composed of two equivalents of the metal with three of their other respective ingredients, and the present instance may be represented as 2 I. 56 + 3 C. 105, the same proportions being thus preserved.

IRON AND SULPHUR.

Proto-sulphuret of Iron.—44.

(1 I. 28 + 1 S. 16.)

(§ 296.) THE best method of forming

the proto-sulphuret of iron is to take a bar of the metal at a glowing red heat and rub it well with a roll of sulphur: the compound will fall down in drops. It is distinguished by being attracted by the magnet, and is sometimes found in nature. It is composed of

1 equivalent of iron	-	-	28
1 ditto sulphur	-	16	—
			44

Bisulphuret of Iron.—60.

(1 I. 28 + 2 S. 32.)

(§ 297.) THE bisulphuret cannot be artificially formed, but is an abundant natural product, and has received the name of *iron pyrites*. It is of a bronze yellow colour, and is often found in crystals. When heated to redness it loses half its sulphur, and becomes converted into the proto-sulphuret. It is not attracted by the magnet. It is composed of

1 equivalent of iron	-	-	28
2 ditto sulphur	-	32	—
			60

IRON AND CARBON.

Steel.

(§ 298.) IRON, as it flows from the furnaces in which it is reduced, in which state it is called cast iron, contains, amongst other ingredients, a very considerable, but variable proportion of carbon, amounting sometimes to $\frac{1}{40}$ th of its weight. In this state it is neither ductile nor malleable, but very brittle.

If the purest malleable iron be surrounded by charcoal in powder, and exposed to a long-continued red heat, it unites with about $\frac{1}{150}$ th of its weight of carbon, and acquires new properties, being converted into steel: it becomes much harder, more sonorous and elastic, and takes a much higher polish. When ignited and suddenly cooled, it is rendered so hard and brittle as to be unfit for any useful purpose. To fit it for use it requires what is termed *tempering*; which consists in heating it up to a certain point, that varies with the purpose to which it is afterwards to be applied. These points are, to a certain extent, indicated by the various colours which the metal assumes on its surface.

The experiment has often been tried of inclosing small diamonds in cavities in soft iron, and igniting the mass;

when the former disappear, and the inner surface of the latter is found is converted into steel (§ 151).

Steel may be distinguished from pure iron by applying a drop of any weak acid to its surface, when the charcoal which it contains will be exhibited by a black stain.

Plumbago.

(§ 299.) THE well-known substance of which black-lead pencils are made is a true *carburet* of iron, containing about 10 per cent. of the metal and 90 of pure carbon. It is a natural product of considerable value, and has not hitherto been formed by art.

ALLOYS OF IRON.

(§ 300.) IRON may be alloyed with various metals; but the most useful combination of this nature is that with tin. Iron plates, previously cleaned by a weak acid, and dipped into that metal when melted, become perfectly plated with it, and are very extensively employed in the arts.

ZINC.—34.

(§ 301.) ZINC is known in commerce by the name of *spelter*; but usually contains an admixture of lead and sulphur. When purified from these, it is of a brilliant white colour, inclining to blue. Its specific gravity is about 6.8. Under particular circumstances of temperature, it is malleable, and may be beaten into leaves or drawn into wire. It melts at about 725° of Fahrenheit's scale, and crystallizes on cooling. It is easily volatilized, and may be purified by distillation.

ZINC AND OXYGEN.

Oxide of Zinc.—42.

(1 Z. 34 + 1 O. 8.)

(§ 302.) WHEN zinc is exposed to a temperature in the air very little above its melting point, it burns with a dazzling flame, of a bluish tint; and its oxide flies up in the form of white flowers, formerly called *flowers of zinc*, or *philosophical wool*. This oxide, which is the only one known, is, however, fixed in the fire, and may be melted into a clear yellow glass. The same oxide is formed when the vapour of water is brought into contact with the metal in a state of ignition. This decomposition

takes place with great rapidity. The oxide is composed of

1 equivalent of zinc	-	-	34
1 ditto oxygen	-	-	8
			42

It constitutes a salifiable base.

ZINC AND CHLORINE.

Chloride of Zinc.—70.

(1 Z. 34 + 1 C. 36.)

(§ 303.) WHEN zinc is burned in chlorine, a solid, grey, semi-transparent substance is formed, which is the only known chloride of that metal. It is as soft as wax, and melts at a temperature a little above 212° Fah. It rises in vapour at a heat below ignition. Its taste is intensely acrid, and it corrodes the skin. It dissolves in water, with the evolution of much heat. It may also be procured by heating together zinc filings and bichloride of mercury (corrosive sublimate). Its analysis, though not exact, agrees sufficiently with the assumption that it is a compound of

1 equivalent of zinc	-	-	34
1 ditto chlorine	-	-	36
			70

ALLOYS OF ZINC.

(§ 304.) ZINC is capable of being alloyed with many of the metals. It forms particularly useful compounds with copper, which, in different proportions, are known by the names of *brass*, *pinchbeck*, *Dutch gold*, *Prince Rupert's metal*, &c.

CADMIUM.—56.

(§ 305.) CADMIUM has only been very lately discovered amongst the ores of zinc, and has chiefly been derived from a sublimate which rises before that metal in the process for obtaining it by distillation. It resembles tin very nearly in colour, lustre, and the crackling sound which it yields when bent. It is harder and more tenacious than that metal. It may be drawn into fine wire, and reduced into thin plates. Its specific gravity is about 8.6. It melts at a temperature below redness, and is volatilized almost as readily as mercury. Its vapour condenses in drops, which have a crystalline appearance when cold.

CADMIUM AND OXYGEN.

Oxide of Cadmium.—64.

(1 C. 56 + 1 O. 8.)

(§ 306.) CADMIUM is little altered

exposure to the air at common temperatures, but, when heated in open vessels, it burns and flies off in smoke, which falls and forms a very fixed oxide of a brownish-yellow colour. It is insoluble in water, and is the only known compound of the metal with oxygen. It is constituted of

1 equivalent of cadmium - - 56
1 ditto oxygen - - 8

—
64

It is soluble in the acids.

MANGANESE.—28?

(§ 307.) MANGANESE is never found native in the metallic state, the substance commonly known in the arts by that name being an impure oxide. The metal is extremely refractory, and more difficult of fusion even than iron. It is of a dusky-white colour, but bright and shining in its fracture. Its specific gravity is about 8.0. It is very brittle, soon tarnishes on exposure to the air, and crumbles into a brown powder.

MANGANESE AND OXYGEN.

Protoxide of Manganese.—36.

(1 M. 28 + 1 O 8.)

(§ 308.) Considerable uncertainty still exists with regard to the various compounds of manganese with oxygen. The protoxide may be formed by mixing the deutoxide (presently to be described) with charcoal, and exposing it to a strong red heat; or by passing a current of hydrogen over the same oxide heated to redness in a porcelain tube. When pure it is of a green colour, but speedily becomes brown from the absorption of oxygen. It may also be produced by dissolving the common black oxide of manganese in sulphuric or nitric acid, adding a little sugar, and precipitating, by solution of potash; a white powder may be thus collected, which is a hydrate, and which being heated to redness out of the contact of air, gives off its water, and yields the oxide. It takes fire when gently heated, and is converted into the deutoxide.

Deutoxide of Manganese.—40.

(1 M. 28 + 1½ O. 12.)

(§ 309.) THE deutoxide of manganese

is readily procured by exposing the peroxide to a low red heat. It is of a brown colour. It presents the anomaly of an equivalent and a half of oxygen united to the metal. When exposed to the air it slowly absorbs oxygen, and returns to the state of peroxide. Both these oxides form the bases of saline compounds.

Peroxide of Manganese.—44.

(1 M. 28 + 2 O. 16.)

(§ 310.) THIS compound is found native in abundance, and is used in the arts for discolouring glass, and for the manufacture of chlorine for bleaching. It is commonly of an earthy appearance, and mixed with other ingredients; but it is not unfrequently met with in crystals of a black colour and metallic lustre. It undergoes no change on exposure to the air. It is insoluble in water, and does not unite either with acids or alkalies. It has the singular property of inflaming linseed oil, when previously well dried and kneaded with it. On exposure to red heat it gives out oxygen (§ 36), and is converted, as above stated, into deutoxide.

Manganeseous and Manganic Acids.

(§ 311.) THERE is reason to suppose that manganese unites with additional proportions of oxygen, and forms two distinct acids; but the subject requires further investigation before it can be considered as finally determined. When the peroxide of manganese is mixed with an equal weight of nitre, and exposed to a red heat, a green-coloured mass is obtained, which has long been known by the name of *mineral chameleon*. On dissolving this substance in water, a green solution is obtained; the colour of which soon changes in succession to blue, purple, and red, and ultimately disappears entirely. The experiment may be varied by putting equal quantities of this substance into two glass vessels, and pouring into the one hot, and into the other cold water. The hot solution will have a beautiful green colour, and the cold a deep purple. The shades will vary as the temperature alters. These green and red colours have been ascribed to the successive formation of the two acids.

CHAPTER IX.

On the Metals which absorb and retain Oxygen at high temperatures, and decompose Water at common temperatures, or the ALKALINE METALS,

Potassium, Calcium,
Sodium, Barium,
Lithium, Strontium,

and their Binary compounds.

(§ 312.) WE come now to those metals whose attraction for oxygen is of the most intense degree; which absorb it from the atmosphere, retain it at the highest heats, and detach it from water even at common temperatures. Their oxides had, for ages, resisted all attempts to analyse them, when at length they were found to yield to the decomposing energy of the voltaic pile. The secret of their composition being once developed, some of them have been since reduced by other means; but the majority can only yet have their prevailing affinity temporally suspended by the electric repulsion. There is a striking resemblance between the properties of the oxides of all these metals; they are emphatically denominated *alkalies*. Their taste is hot, bitter, and caustic: they are more or less soluble in water: they change the colours of vegetable blues to green, and yellows to brown; characters which correspond with those which we have described as existing in the volatile alkali, ammonia (§ 79).

POTASSIUM.—40.

(§ 313.) IF a thin piece of hydrate of potash, slightly moistened, be placed between two plates of platinum connected with the extremities of a voltaic apparatus of 200 double plates, four inches square, it will soon undergo fusion; oxygen will separate at the positive pole, and small metallic globules will appear at the negative surface. The metal can only thus be obtained in very small quantities, but quite sufficient to determine its characters. After this important discovery was made, it was found that the same decomposition might be effected by the power of elective affinity, assisted by strong heat, and the metal be produced in much greater abundance. If iron-turnings be heated to whiteness in a curved gun-barrel, and potash melted and made slowly to come in contact with the turnings, the air being carefully excluded, potassium will be

formed and collect in the part of the tube kept cool for that purpose.

This extraordinary metal is solid at the ordinary temperature of the atmosphere; but it is soft, and easily moulded by the fingers. In colour and lustre, when newly cut, it exactly resembles mercury. It is perfectly opaque, and a good conductor both of heat and electricity. It is lighter than water; its specific gravity, at 60°, being 0.865. It is not perfectly fluid till its temperature reaches 150° Fah.; and it may be sublimed at a red heat, provided the air be perfectly excluded. When heated in the air it burns with a white flame; and, when thrown upon water, it acts upon that fluid with great violence, swimming upon its surface, and burning with great splendour. It oxidizes rapidly in the air, and can only be preserved under naphtha or other light fluids, into the composition of which oxygen does not enter, or in glass tubes hermetically sealed.

POTASSIUM AND OXYGEN.

Protoxide of Potassium, or Potash.—48.

(1 P. 40 + 1 O. 8.)

(§ 314.) THE protoxide of potassium, commonly called potash, is always formed when potassium is put into water, or exposed to dry air or oxygen gas. By the first process, even when the solution is evaporated to dryness, and exposed to a red heat, it retains a proportion of water; by the second it is anhydrous. The anhydrous oxide may also be obtained by decomposing nitrate of potash (nitre), at a red heat, in a vessel of gold. In this state it is white, extremely caustic, and fusible a little above a red heat. It has an intense affinity for water, which it absorbs from the air. When once combined with it, it cannot be wholly expelled by the most intense heat. The solid hydrate of potash is composed of

1 equivalent of potash	-	48
1 ditto water	-	9
		—
		57
		—

It is in this state that it is commonly met with. It is easy to ascertain the quantity of oxygen which enters into the composition of potash by the volume of hydrogen liberated during the action of potassium on water; for, when the metal is plunged at once under that fluid, it is oxidized without the evolution of light and heat; and each grain de-

taches 1.06 cubic inch of hydrogen gas. Hence 75 parts of potassium condense 15 parts of oxygen to become potash, and 15 : 75 :: 8 : 40; therefore potash is constituted of

1 equivalent of potassium	-	-	40
1 ditto oxygen	-	-	8
			—
			48
			—

The potash of commerce is obtained, in an impure state, by the incineration of vegetable matters, and hence is designated as the *vegetable alkali*. The purest is distinguished by the name of *pearlash*. To render it perfectly pure for chemical purposes, *pearlash* should be dissolved in twice its weight of boiling water: an equal weight of fresh burned lime, reduced to a powder by slaking, must then be equally diffused through it, and the whole boiled and stirred in an iron vessel for half an hour. The clear solution, carefully separated from the sediment, must next be evaporated to dryness in a silver dish. Pure alcohol will now take up only the perfectly pure hydrate of potash, which may be obtained in the solid form by evaporating or distilling off the spirit in silver vessels. The hydrate of potash has an intensely acrid taste, and destroys the texture of animal and vegetable substances. It changes blue vegetable colours to green, and neutralizes acids without effervescence. It rapidly attracts moisture and carbonic acid from the air. It is extensively used in several manufactures.

Peroxide of Potassium.—64.

(1 P. 40. + 3 O. 24.)

(§ 315.) WHEN potassium is burned in the open air, or in oxygen gas, it is converted into an orange-coloured substance, which is the peroxide of the metal. It may likewise be formed by passing a current of oxygen over potash at a red heat. When this peroxide is thrown into water, a solution of potash (or protoxide) is formed, and oxygen is given off with effervescence. It is composed of

1 equivalent potassium	40
3 ditto oxygen	24
	—
	64
	—

When it is fused, and brought into contact with combustible bodies, they burn vividly in the excess of its oxygen.

POTASSIUM AND CHLORINE.
Chloride of Potassium.—76.
(1 P. 40. + 1 C. 36.)

(§ 316.) WHEN small pieces of potassium are introduced into chlorine, the inflammation is very intense. Each grain absorbs 1.1 cubic inch of the gas, and the white saline body which is formed, is constituted of

1 equivalent potassium	40
1 ditto chlorine	36
	—
	76
	—

Chloride of potassium is soluble in water, and crystallizes from its solution by evaporation. It has a bitter, disagreeable taste.

The attraction of chlorine for potassium is stronger than that of oxygen: for both the oxides are decomposed by that body; the chloride being produced and oxygen extricated.

ALLOYS OF POTASSIUM.

(§ 317.) POTASSIUM combines rapidly with mercury; and the union is effected by merely bringing the two metals in contact at the temperature of the air. The amalgam is soft and malleable; but its solidity and brittleness increase with the proportion of potassium. This compound may be obtained by a very easy process by those who possess a voltaic pile of only twenty plates. A thin stratum of mercury is made to cover the bottom of a flat glass dish, of about two inches diameter: this is covered with a strong solution of pure potash; an iron wire must connect the negative pole of the battery with the mercury, and a platinum wire from the positive pole must dip into the alkaline solution within about a line of the surface of the mercury. With such an arrangement, more than 1200 grains of mercury will become solid in twenty-four hours.

The amalgam rapidly attracts oxygen from the air; and the mercury is restored to its former state. It has the property of dissolving all the metals, and even of acting upon platinum.

Potassium unites also with gold, silver, and copper; and when the alloys are thrown into water, they are decomposed, a solution of potash is formed, and the metals are separated unaltered.

SODIUM.—24.

(§ 318.) SODIUM may be obtained by exactly the same electrical and chemical processes as potassium, by acting upon

pure hydrate of soda. It requires, however, a stronger voltaic power, and a higher degree of heat to effect the decomposition. The metal is as white as silver, possesses great lustre, and is a good conductor of heat and electricity. It is very malleable, and perfectly opaque. It is lighter than water; its specific gravity being 0.972. It is less fusible than potassium, not becoming perfectly liquid till it acquires a temperature between 180° and 190° F. When exposed to the atmosphere, it tarnishes; but is not changed in air that has been artificially dried. When thrown upon water, it produces a violent effervescence and hissing noise, but does not inflame. It gradually diminishes with great agitation; a solution of soda is produced, and hydrogen escapes. When heated to its fusing point in air, or oxygen gas, it becomes rapidly oxidated; but does not inflame till nearly red hot, when it burns with a white light, accompanied with red sparks. Like potassium, it is best preserved under the surface of pure naphtha.

SODIUM AND OXYGEN.

Protoxide of Sodium, or Soda.—32.

(1 S. 24 + 1 O. 8.)

(§ 319.) THE protoxide of sodium, or soda, is formed when the metal is burned in perfectly dry atmospheric air. It is also formed when sodium is thrown into water, and its composition may be determined by the quantity of hydrogen which is liberated. Upon evaporating, the solution, however, obtained by the last means, the soda is obtained in the form of a *hydrate*, from which the last portions of water cannot be expelled by any degree of heat. It is composed of

1 equivalent oxide	32
1 ditto water	9
	—
	41
	—

the oxide itself being a compound of

1 equivalent of sodium	24
1 ditto oxygen	8
	—

making the equivalent of soda 32

The solid hydrate is easily fusible by heat, and extremely caustic; it is soluble in water and alcohol, and possesses all the alkaline properties in an eminent degree. It is found in commerce in an impure state, and is largely used in many important manufactures. It may be purified by a similar process

to that for obtaining pure potash. Under the name of *nutron*, it is found native in mineral seams or crusts, and hence has been called the *mineral alkali*. It is also largely produced by the incineration of sea-weeds.

Peroxide of Sodium.—40.

(1 S. 24 + 2 O. 16.)

(§ 320.) WHEN Sodium is strongly heated in an excess of pure oxygen, an orange-coloured substance is formed, which is the peroxide of the metal. It is very fusible, and a non-conductor of electricity. When acted upon by water, it gives off oxygen and forms a solution of soda. It deflagrates when heated with combustible bodies. It is constituted of

1 equivalent of sodium	-	24
2 ditto oxygen	-	16
		—
		40
		—

SODIUM AND CHLORINE.

Chloride of Sodium, or Common Salt.—60.

(1 S. 24 + 1 C. 36.)

(§ 321.) Sodium burns in chlorine, and is converted into a white compound, having all the characters of the well-known substance *common salt*. The same product may also be formed by heating the metal in muriatic acid gas, when hydrogen is liberated and the chloride formed. It is an abundant product of nature, and is become a necessary ingredient of the food of man, and of essential utility in many of the arts. It is soluble in water, and crystallizes from its solution when the water is evaporated. It fuses, but does not undergo any other change from a strong heat. The attraction of sodium for chlorine is not so strong as that of potassium: hence, when the latter metal and common salt are heated together, sodium is obtained. The chloride of sodium is composed of

1 equivalent of sodium	-	24
1 ditto chlorine	-	36
		—

and the equivalent of common salt is 60

LITHIUM.—10.

(§ 322.) LITHIUM has very lately been discovered in the state of an oxide or alkali in two or three rare minerals; and in this respect offers a strong contrast to the abundant distribution of the vegetable and mineral alkalies which we have just been describing. It has

been reduced to the metallic state by the power of the voltaic battery; but it burned again so rapidly, that it was only observed to be of a white colour, and much to resemble sodium.

LITHIUM AND OXYGEN.

Lithia.—18.

(1 L. 10 + 1 O. 8.)

(§ 323.) PURE oxide of lithium, or lithia, has a very sharp, burning taste, and rapidly corrodes the cuticle, like potash. It is soluble in water with the evolution of heat, but very sparingly soluble in alcohol. It strongly possesses all the alkaline properties. When heated in contact with platinum, it fuses, and acts upon the metal. If exposed to the air, it does not deliquesce, but rapidly attracts carbonic acid. It is composed of

1 equivalent of lithium	-	-	10
1 ditto oxygen	-	-	8

and the equivalent of lithia is - 18

CALCIUM.—20.

(§ 324.) CALCIUM has only hitherto been obtained in minute quantities by the power of electrical repulsion, acting upon lime; which has by these means been proved to be an oxide of the metal. The process may be repeated, with a battery of sufficient power, by forming some pure lime into a paste with water, and placing a globule of mercury in a small cavity in its surface. It may be placed upon a metallic plate connected with the positive wire of the battery; while the negative wire is made to dip into the mercury. When the process has been continued sufficiently long, an amalgam of calcium is obtained, which may be put into a small retort with naphtha enough to cover it. Upon applying heat the naphtha first rises in vapour, then the mercury, and the calcium remains fixed. It has been obtained in such small quantities, that but little is known of its nature. The metal is white, with the colour and lustre of silver. When gently heated in air, it takes fire, and burns with an intense white light into lime. When the amalgam of calcium is thrown into water, hydrogen is given off, and a solution of lime is formed.

CALCIUM AND OXYGEN.

Protoxide of Calcium, or Lime.—28.

(1 C. 20 + 1 O. 8.)

(§ 325.) FROM the quantity of hydrogen

evolved by the action of calcium upon water, it has been calculated that lime is composed of

1 equivalent of calcium	-	-	20
1 ditto oxygen	-	-	8

making the equivalent of lime - 28

Lime is a well-known and highly-important substance, whose compounds are widely distributed in all the kingdoms of nature. When pure, in which state it may be obtained by exposing white marble, or calcareous spar to a strong red heat, it is a soft white substance of the specific gravity of 2.3. It is perfectly fixed in the fire, and requires an intense heat for its fusion; but it remarkably promotes the fusion of earthy bodies, and is therefore used in metallurgy as a powerful *flux*. Its taste is caustic, alkaline, and astringent. It is sparingly soluble in water, requiring at 60° Fah. 750 times its weight to effect the solution. It is rather less soluble in hot than in cold water; so that when lime-water is boiled, the lime is precipitated. It renders vegetable blue colours green, and yellows brown. Lime absorbs moisture from the air, and becomes converted into a hydrate, which is also formed when *quick lime* (as it is commonly called) undergoes the process of *slaking*. This consists in sprinkling it with water, which it greedily absorbs; giving out, at the same time, a great quantity of heat. The hydrate is a white bulky powder, which consists of

1 equivalent of lime	-	-	28
1 ditto water	-	-	9

37

It parts with its water at a red heat.

Deutoxide of Calcium.—36.

(1 C. 20 + 2 O. 16.)

(§ 326.) BY passing oxygen gas over ignited lime, the gas is absorbed, and a peroxide of calcium formed, which is believed to be composed of

1 equivalent of calcium	-	-	20
2 ditto oxygen	-	-	16

36

CALCIUM AND CHLORINE.

Chloride of Calcium.—56.

(1 C. 20 + 1 Ch. 36.)

(§ 327.) THE chloride of calcium has not been directly made, on account of the great scarcity of the metal; but when pure lime is heated in chlorine, the

oxygen is evolved and the chloride produced. It is composed of

1 equivalent of calcium	-	-	20
1 ditto chlorine	-	-	36
			—
			56
			—

When it is exposed to the air, it deliquesces rapidly; and the solution is of a thick oily consistence, and of a bitter acid taste. Its attraction for moisture is so great, that it is very commonly employed in chemical experiments, for drying gases, and other products (§ 84 and 174), by passing them over its surface. It may be crystallized, and when mixed in this state with new-fallen snow, a degree of cold may be produced sufficient to freeze mercury.

BARIUM.—70.

(§ 328.) BARIUM has been obtained in small quantities, by a process exactly similar to that for obtaining calcium, the paste being formed of a mineral, called *Carbonate of Barytes*. The residue of the distillation in this case is a dark-grey metal, whose lustre is inferior to that of cast-iron. It fuses at a heat below redness; and if heated to redness, is converted into vapour, which acts violently upon glass. From some experiments which have been made upon it, it is probably four or five times heavier than water. When exposed to the air, it falls into a white powder, which is the protoxide of the metal; and when thrown into water, it acts with great violence, producing hydrogen gas, and a solution of the oxide. When heated in the air, it combines with its oxygen more rapidly, burning with a deep-red light.

BARIUM AND OXYGEN.

*Protoxide of Barium, or Baryta.**—78.

(1 B. 70 + 108.)

(§ 329.) THE oxide formed, as above, by the combustion of metallic Barium, may more readily be obtained by the combination, at an intense heat, of *carbonate of baryta* mixed with charcoal. This salt is a native product, and may also be prepared by art. The more simple operation, however, is to dissolve the carbonate in nitric acid, and then to decompose the nitrate; which may be effected by a moderate heat.

Baryta, when pure, has a sharp caustic

* From a Greek word, signifying *heavy*, from its great specific gravity.

taste; changes vegetable blue colours to green, and neutralizes the acids. It is poisonous, as are all its soluble compounds. It is generally obtained in the form of a grey powder of the specific gravity of about 4. It is insoluble in pure alcohol, but has a very strong affinity for water. It may be *slaked* in the manner of *quicklime*, but with the evolution of a much greater degree of heat. The *hydrate* thus formed is composed of

1 equivalent of baryta	-	78
1 ditto water	-	9
		—
		87
		—

It melts at a red heat, but does not part with its water at the highest temperature of a smith's forge. It dissolves in twice its weight of boiling water, and in 20 parts of water at the temperature of 60° Fah. The boiling solution, upon cooling, deposits regular crystals, which consist of

1 equivalent of barytes	-	78
20 ditto water	-	180
		—
		258

19 of which are driven off by a red heat. They communicate a yellowish colour to the flame of alcohol. The protoxide is composed of

1 equivalent of barium	-	70
1 ditto oxygen	-	8
		—
		78
		—

Peroxide of Barium.—86.

(1 B. 70 + 2 O. 16.)

(§ 330.) BARIUM may be made to unite with a further proportion of oxygen. When pure barytes is ignited in oxygen the gas is rapidly absorbed, and a grey compound formed. It is best prepared by passing a current of dry oxygen over the oxide placed in a glass tube horizontally fixed in a furnace, and heated to redness. It is composed of

1 equivalent of barium	-	70
2 ditto oxygen	-	16
		—
		86
		—

(§ 331.) It is from this compound that the *oxygenized water*, before described (§ 54.), is prepared. When acted upon by liquid muriatic acid it abandons part of its oxygen, and is reduced to the state of protoxide; which is dissolved by the acid, while the oxygen unites with the water. Sulphuric acid carefully added

to this solution forms an insoluble precipitate with the barytes, and the muriatic acid is again set free; which is thus made to act upon successive portions of the peroxide, until the water is fully saturated with oxygen. The muriatic acid is then removed by dropping in some sulphate of silver; when another insoluble precipitate falls down and the remaining sulphuric acid is abstracted by a solution of pure barytes. The perfect success of this process, though simple in theory, depends upon many practical precautions, and must be carried on in vessels surrounded with ice.

Barium and Chlorine.

Chloride of Barium.—106.

(1 B. 70 + 1 C. 36.)

(§ 332.) WHEN pure baryta is heated in chlorine, oxygen gas is liberated, and a chloride of barium formed—which is composed of

1 equivalent of barium -	70
1 ditto chlorine -	36
	—
	106
	—

Strontium.—44.

(§ 333.) STRONTIUM may be obtained, in minute quantities, by the same process as barium; substituting the carbonate of strontia,* which is a native product, for the carbonate of baryta. It resembles barium, is fusible with difficulty, and not volatile. It decomposes water with the evolution of hydrogen, and is converted into an oxide by exposure to the air.

Strontium and Oxygen.

Protoxide of Strontium, or Strontia.—52.

(1 S. 44 + 1 O. 8.)

(§ 334.) THE protoxide of strontium, or strontia, may be obtained by exposing nitrate of strontia to a strong red heat. It is a grey substance which possesses distinct alkaline properties. It may be slaked with water, which causes an intense heat. The solid hydrate is composed of

1 equivalent of strontia -	52
1 ditto water -	9
	—
	61
	—

* So called from Strontian in Scotland, where it was first discovered.

and strontia of

1 equivalent of strontium	44
1 ditto oxygen -	8
	—
	52
	—

The hydrate fuses at a red heat; but its water cannot be driven off by the strongest temperature of a blast furnace. It is very soluble in boiling water, which deposits it in crystals, upon being allowed to cool undisturbed, which are composed of one equivalent of the oxide, and twelve of water. They are insoluble in alcohol, but impart a blood red colour to its flame.

It differs from baryta in not being poisonous: but its taste is acrid.

CHAPTER X.

On the Metals which are generally analogous to those of the last class, but whose Oxides are insoluble in water, and insipid: or the

EARTHY METALS.

Magnesium. Yttrium. Aluminium. Glucinum. Zirconium.

(§ 335.) THE existence of the remaining class of metals rests, for the most part, upon imperfect results of experiment, but upon strong analogy. Their oxides, in which form only they exist in nature, have long been known by the general name of *earths*: they are not convertible to the metallic state by any of the ordinary methods of reduction, and scarcely even by the utmost exertion of scientific refinements: they are insipid, and destitute of the acrid taste of the alkalies, but constitute salifiable bases and perfectly neutralize the acids. These earthy metals have been called Magnesium, Glucinum, Yttrium, Aluminium, and Zirconium.

MAGNESIUM.—12.?

(§ 336.) BY exposing *Magnesia*, in contact with mercury, for a long time to the influence of a powerful voltaic battery, an amalgam may be obtained; which, by distillation out of the contact of the atmosphere, affords a dark grey metallic film. It has been collected in such very minute quantities, as scarcely to suffice for determining its properties. It is, however, infusible at a very high temperature, but burns with a red light, and is converted into a white powder possessing the properties of magnesia. When thrown into water, it sinks to the bottom, effervesces slowly, and becomes covered with the same white substance.

MAGNESIUM AND OXYGEN.

Oxide of Magnesium or Magnesia.—20.

(1 M. 12 + 1 O. 8.)

(§ 337.) THE proportion in which the metallic base of magnesia combines with oxygen has not been determined by direct experiment; but it is inferred from the combinations of the oxide, that magnesia is a compound of

1 equivalent of magnesium	12
1 ditto oxygen	- 8
and that its combining proportion is	— 20

Pure magnesia may be obtained by exposing carbonate of magnesia to a strong red heat; and is commonly to be met with under the name of calcined magnesia. It is well known as a much-used medicine. It is a white, soft powder, having a specific gravity of 2.3. It is infusible, and possesses neither taste nor smell. It renders the colour of violets green when suspended in water; but is so insoluble, that if the water with which it has been mixed be afterwards filtered, it no longer affects blue vegetable colours. It absorbs a quantity of that fluid with the production of heat, and is converted into a hydrate. The water may, however, be again expelled by a red heat. Magnesia is abundantly distributed by nature in the mineral kingdom, entering largely into the composition of extensive rock formations; and also forms a considerable proportion of the ingredients of sea water, from which it is chiefly obtained for the purposes of commerce.

GLUCINUM.—20 ?

(§ 338.) BY heating a peculiar earth called glucina,* with potassium, the latter has been converted into potash; and dark coloured particles, possessing a metallic lustre, were disseminated through the mass, which regained the earthy appearance by being heated in the air, and by the action of water. Hence it is probable that the earth is a compound of oxygen and a peculiar metal to which the name of glucinum has been given.

Oxide of Glucinum, or Glucina.—28.

(§ 339.) GLUCINA has been ascertained to exist only in three rare minerals, viz. the beryl, the emerald, and the euclase. It has been separated from the other ingredients with which it is combined, in the

form of a fine, white, soft powder. It has the property of adhering to the tongue like pure clay. Its specific gravity is about 3. It has no action upon vegetable colours, and is insoluble in water, with which however it may be formed into a ductile paste. It is soluble in liquid potash or soda, but not in a solution of ammonia; it is, on the other hand, completely taken up by carbonate of ammonia, and is precipitated from it by boiling. This latter property distinguishes it from the other earths with which it might be liable to be confounded. It combines with the different acids, forming salts which possess a sweet astringent taste.

YTTRIUM.—34 ?

(§ 340.) THE evidence of the metallic existence of yttrium is of the same nature, and obtained by the same means as that of the last species.

Oxide of Yttrium, or Yttria.—42.

(§ 341.) YTTRIA is a peculiar earth of still more rare occurrence even than glucine, having been chiefly found in a very scarce mineral from Ytterby in Sweden, whence it derives its name. When separated from its other associates in the compound, it is perfectly white, and very ponderous, its specific gravity being 4.8. It is devoid of taste and smell, and is smooth to the touch. It is insoluble in water, and infusible except at a very intense heat. It is not acted upon by pure alkalies, but is slightly soluble in carbonate of ammonia. It forms combinations with most of the acids.

ALUMINUM.—10 ?

(§ 342.) TILL very lately, the evidence of the existence of the metallic base of alumine (or pure clay) was of the same imperfect nature as that of the other earths which we have just enumerated: the skilful application of the powers of elective attraction has, however, very recently effected its decomposition in a more satisfactory way. For this purpose dry chloride of aluminum (presently to be described) is put into a platina crucible with about a tenth of its weight of potassium, and the mixture gently heated over a spirit lamp, and afterwards allowed to cool gradually. The chlorine passes to the potassium and leaves the aluminum. Upon throwing the mass into water the metal falls to the bottom of the vessel in a granular

* From a Greek word signifying *sweet*: many of its combinations having a sweet taste.

state, like gunpowder. It possesses a metallic lustre, approaching to that of tin. When the powder is rubbed upon any hard substance with a burnisher, the particles adhere together and form a surface which strongly reflects the light. It has a powerful affinity for oxygen, but is not readily altered by exposure to either air or water at common temperatures. When heated in oxygen gas it burns with great splendour, and the evolution of intense heat which is sufficient to partially fuse the alumine, or oxide, which is formed, and which is one of the most infusible substances in nature. Aluminum is perfectly fixed at the highest temperatures to which it has been possible to expose it.

ALUMINUM AND OXYGEN.

Oxide of Aluminum, or Alumine.—18?

(1 A. 10 + 1 O. 8.)

(§ 343.) THE oxide of aluminum, or alumine, is most abundantly distributed in the mineral kingdom of nature. It is found nearly in a state of purity in the precious gems, the ruby and the sapphire; and is a constituent of the oldest rocks and the most recent alluvial deposition. The different kinds of clay, of which porcelain, pipes, and bricks are made, consist of the hydrate of alumine in various degrees of purity. It may be obtained free from the admixture of other earths, for chemical purposes, by precipitating a solution of alum in water, by ammonia or the carbonates of the fixed alkalies; a white, bulky, hydrate of alumine is thus obtained, which, when carefully washed, and heated to whiteness, affords the pure anhydrous earth.

Pure alumine has neither taste nor smell; and does not affect the colours of vegetables. It is not soluble in water, but when moistened with that fluid, forms with it a cohesive ductile mass. It has a strong affinity for moisture, and after ignition greedily absorbs it from the atmosphere, to the amount of half its weight. It is capable of combining both with the fixed alkalies, and with acids, but is very sparingly taken up by the volatile alkali, and not by the alkaline carbonates.

It forms permanent combinations with the colouring matter of different organic substances, and is much used in the processes of dyeing and calico printing.

ALUMINUM AND CHLORINE.

Chloride of Aluminum, 46?

(1 A. 10 + 1 C. 36.)

(§ 344.) CHLORIDE of aluminum may be produced by the direct combination of its two ingredients. It may be more easily procured by calcining pure alumine intimately mixed up with sugar and oil, and passing chlorine over the mixture at a red heat. The charcoal of the sugar and the oil abstracts the oxygen of the alumine, and carbonic oxide is formed: the aluminum at the same time unites with the chlorine. The chloride of aluminum is a yellow substance, which rises in vapour at a temperature of 212°. It attracts moisture rapidly from the air and deliquesces. The solution is sensibly acid.

ZIRCONIUM.

(§ 345.) THE metallic base of zirconia (a very rare product of nature) has been lately disengaged by heating potassium with a salt called *fluato of zirconia and potash* carefully dried. The decomposition is effected at a temperature below redness. The residue, after washing in boiling water, and digestion in diluted muriatic acid, is pure zirconium.

It is thus obtained in the form of a black powder. When heated in the open air, it takes fire at a temperature below redness, burns very brightly, and is converted into the earth. When rubbed between two hard surfaces, it assumes the form of shining scales of a dark grey colour.

Oxide of Zirconium, or Zirconia.

(§ 346.) THE oxide of zirconium has only been detected in two or three rare minerals (the *zircon* of Ceylon, and the *hyacinth* from France.) It is an earthy substance, much resembling alumine in external character. It has neither taste nor smell, and is quite insoluble in water. Its colour is white, and its specific gravity about 4.3. It forms salts with the different acids, and is sparingly dissolved by the alkaline carbonates, but not by pure alkalies.

(§ 347.) HAVING now completed the list of the metals, we shall subjoin two tables, similar to those of the non-metallic elements, which may assist in recalling their arrangement, and fixing upon the mind the equivalent proportions in which they are disposed to combine.

TABLE III.
METALLIC ELEMENTS.

	Electro-Negative.		Electro-Positive.	No. of Equi- valents.
Oxides reducible by mere heat. (<i>Noble Metals.</i>)	.	.	Mercury . . .	200
	.	.	Silver . . .	110
	.	.	Gold . . .	200
	.	.	Platinum . . .	96
	.	.	Palladium . . .	56
	.	.	Rhodium . . .	44
	.	.	Iridium . . .	?
	.	.	Osmium . . .	?
	.	.	Nickel . . .	30
Do not decompose water at any tem- perature.	.	.	Lead . . .	104
	.	.	Tellurium . . .	29
	.	.	Copper . . .	64
	.	.	Bismuth . . .	71
	.	.	Titanium . . .	?
	.	.	Cobalt . . .	?
	.	.	Cerium . . .	?
	.	.	Uranium . . .	?
	.	.	Antimony . . .	44
	.	.	Columbium . . .	144
	.	.	Tungsten . . .	96
	.	.	Chromium . . .	28
	.	.	Molybdenum . . .	48
	.	.	Arsenic . . .	38
Decompose water at a red heat . . .	.	.	Tin . . .	59
	.	.	Iron . . .	28
	.	.	Zinc . . .	34
	.	.	Cadmium . . .	56
	.	.	Manganese . . .	28
Decompose water at atmospheric tem- peratures. Oxides caustic. . . .	.	.	Potassium . . .	40
	.	.	Sodium . . .	24
	.	.	Lithium . . .	10
	.	.	Calcium . . .	20
	.	.	Barium . . .	70
	.	.	Strontium . . .	44
(Alkaline Metals.)	.	.		
Decompose water be- low a red heat, but oxides insipid . . .	.	.	Magnesium . . .	12
	.	.	Glucinum . . .	20
	.	.	Yttrium . . .	34
	.	.	Aluminum . . .	10
	.	.	Zirconium . . .	?
(Earthy Metals.)	.	.		

TABLE IV.—BINARY COMPOUNDS OF METALLIC ELEMENTS.

Equivalents.		Equivalents.	ACID.	No. of Equivalents.	ALKALINE, OR BASIC.	No. of Equivalents.	NEUTRAL.	No. of Equivalents.
			<i>Electro-Negative.</i>		<i>Electro-Positive.</i>			
1 Mercury	+1 Oxy.		.	.	Protox. of Merc. 208			
Ditto	+2 Ditto		.	.	Perox. of Merc. 216			
Ditto	+1 Chlo.		.	.	.		Protochl. of Mercu. 236	
			.	.	.		(Calomel.)	
Ditto	+2 Ditto		.	.	.		Bichlo. of Mercury 272	
			.	.	.		(Corrosive Sublimate.)	
Ditto	+1 Sulph.		.	.	.		Protosulph. of Mer. 216	
Ditto	+2 Ditto		.	.	.		Bisulphu. of Mer. 232	
1 Silver	+1 Oxy.		.	.	Oxide of Silver 118		Chloride of Silver 146	
Ditto	+1 Chlo.		.	.	.		Sulphuret of Silver 126	
Ditto	+1 Sulph.		.	.	.			
1 Gold	+3 Oxy.		.	.	Oxide of Gold. 224		Sulphuret of Gold 248	
Ditto	+3 Sulph.		.	.	.			
1 Platinum	+2 Oxy.		.	.	Oxide of Platin. 112		Chlo. of Platinum 132	
Ditto	+1 Chlo.		.	.	.		Sulph. of Palladium 72	
1 Palladium	+1 Oxy.		.	.	Oxide of Palladium 64			
Ditto	+1 Sulph.		.	.	.			
1 Nickel	+1 Oxy.		.	.	Oxide of Nickel. 38			
1 Lead	+1 Ditto		.	.	Protox. of Lead 112		Deutoxide of Lead 116	
Ditto	+1½ Ditto		.	.	.		Peroxide of Lead 120	
Ditto	+3 Ditto		.	.	.		Chloride of Lead 140	
Ditto	+1 Chlo.		.	.	.		Sulphuret of Lead 120	
Ditto	+1 Sulph.		.	.	.			
1 Tellurium	+1 Oxy.		.	.	Ox. of Tellurium 37			
1 Copper	+1 Ditto		.	.	Protox. of Copper 72			
Ditto	+2 Ditto		.	.	Perox. of Copper 80		Protochl. of Copper 100	
Ditto	+1 Chlo.		.	.	.		Perchlo. of Copper 136	
Ditto	+2 Ditto		.	.	.			
1 Bismuth	+1 Oxy.		.	.	Oxide of Bismuth 79		Chlo. of Bismuth 107	
Ditto	+1 Chlo.		.	.	.			
1 Cobalt	+1 Oxy.		.	.	Oxide of Cobalt ?			
1 Antimony	+1 Ditto		.	.	Protox. of Antimo. 52			
Ditto	+1½ Ditto							
Ditto	+3 Ditto		Antimonious acid 56					
1 Columbium	+1 Ditto		Antimonic acid 60					
1 Tungsten	+2 Ditto		Columbic acid 162				Oxide of Tungsten 112	
Ditto	+3 Ditto		Tungstic acid 120					
1 Chromium	+1 Ditto		.	.	Protox. of Chromi. 36		Deutox. of Chromi. 44	
Ditto	+2 Ditto		.	.	.			
Ditto	+3 Ditto		Chromic acid 52		.			
1 Molybdenum	+2 Ditto		Molybdous acid 64					
Ditto	+3 Ditto		Molybdic acid 72					
1 Arsenic	+2 Ditto		Arsenious acid 54					
Ditto	+3 Ditto		Arsenic acid 62					
1 Tin	+1 Ditto		.	.	Protox. of Tin 67		Peroxide of Tin 75	
Ditto	+2 Ditto		.	.	.		Protochlo. of Tin 95	
Ditto	+1 Chlo.		.	.	.		Perchloride of Tin 131	
Ditto	+2 Ditto		.	.	.			
1 Iron	+1 Oxy.		.	.	Protox. of Iron 36		Protochlo. of Iron 64	
Ditto	+1½ Ditto		.	.	Perox. of Iron 40		Perchloride of Iron 82	
Ditto	+1 Chlo.		.	.	.		Protosulphu. of Iron 44	
Ditto	+2 Ditto		.	.	.		Bisulphuret of Iron 60	
1 Zinc	+1 Oxy.		.	.	Oxide of Zinc 42			
1 Cadmium	+1 Ditto		.	.	Ox. of Cadmium 64			
1 Manganese	+1 Ditto		.	.	Protox. of Manga. 36			
Ditto	+1½ Ditto		.	.	Deutox. of Manga. 40		Perox. of Manganese 44	
Ditto	+2 Ditto		.	.	.			
1 Potassium	+1 Ditto		.	.	Potash 48		Perox. of Potassium 64	
Ditto	+3 Ditto		.	.	.		Chlo. of Potassium 76	
Ditto	+1 Chlo.		.	.	.			
1 Sodium	+1 Oxy.		.	.	Soda 32		Perox. of Sodium 40	
Ditto	+2 Ditto		.	.	.			

Equivalents.		Equivalents.	ACID.		ALKALINE, OR BASIC.		NEUTRAL.	No. of Equivalents.
			<i>Electro-Negative.</i>	<i>No. of Equivalents.</i>	<i>Electro-Positive.</i>	<i>No. of Equivalents.</i>		
Sodium	. +1	Chlo.	.	.	.	.	Chloride of Sodium	60
1 Lithium.	+1	Oxy.	.	.	.	.	(Common Salt)	
1 Calcium.	+1	Ditto	.	.	Lithia	. 18		
Ditto	+2	Ditto	.	.	Lime	. 28		
Ditto	+1	Chlo.	.	.	.	.	Perox. of Calcium	36
1 Barium .	+1	Oxy.	.	.	.	.	Chloride of Calcium	56
Ditto	+2	Ditto	.	.	Baryta	. 78		
Ditto	+1	Chlo.	.	.	.	.	Perox. of Barium	86
1 Strontium	+1	Oxy.	.	.	.	.	Chloride of Barium	106
1 Magnesium	+1	Ditto	.	.	Strontia	. 52		
1 Glucinum	+1	Ditto	.	.	Magnesia	. 20		
1 Yttrium .	+1	Ditto	.	.	Glucina	. 28		
1 Aluminum	+1	Ditto	.	.	Yttria	. 42		
Ditto	+1	Chlo.	.	.	Alumine	. 18		
1 Zirconium	+1	Oxy.	.	.	Zirconia	. ?	Chlo. of Aluminum	46

In Table III. it may be observed that all the metals are arranged on the electro-positive side; as in their decomposition by electric repulsion, their compounds are invariably reduced at the negative pole of the voltaic battery.

In Table IV. we may remark that the great majority of active combinations (or those compounds which are disposed to enter into further combination, and which are, almost without exception, those of oxygen) also stand in the electro-positive column; whereas in Table II. of the binary combinations of the non-metallic elements all but one are arranged on the electro-negative side. In the former we have a list of 9 acids and 33 *salifiable bases*, and in the latter of 22 acids and 1 base.

Amongst the combinations of oxygen with the metals it is worthy of observation, that there are many instances in which one proportion of oxygen constitutes a base, while a second with the same substance forms an acid. Sometimes one dose of this highly electro-negative element is not sufficient to neutralize the electro-positive energy of the metal, but leaves it as a base in the electro-positive class, while a second completely saturates it, and takes away all further power of combination: at other times, as with chromium, one proportion leaves a decided positive energy, a second completely neutralizes, and a third communicates a negative power.

We must here, however, recal to mind that this division of bodies into electro-negative and electro-positive, is not absolute but relative (§ 33.), and therefore some of the less electro-positive of

the electro-positive class are capable of forming combinations with others of the bases: in this manner, ammonia will unite with several of the metallic oxides, and, more rarely, the fixed alkalies.

The column of the neutral compounds is necessarily very incomplete, as we have only described enough of that class to exemplify the subject: our purpose rather requiring that we should set before the student those substances which again enter into combination, than those in which chemical affinity is neutralized. The binary compounds of iodine, bromine, sulphur, &c. with all the metals, and their multiple proportions, would form an almost interminable list, many of which have never been examined or described, which it would not be consistent with our limits further to pursue.

CHAPTER XI.

On Fluorine and its Compounds.

(§ 348.) WE have stated (§ 98.) that "the class of electro-negative elements contains only four known and one hypothetical (conjectural) body, the existence of which requires to be established by further proof." The properties of the former, viz. oxygen, chlorine, bromine, and iodine, we have already described. We shall now adduce the evidence upon which *fluorine* is added to the list and describe the compounds into which it is believed to enter.

Hydro-Fluoric Acid.—19 ?

(1 F. 18 + 1 H. 1.) ?

(§ 349.) THERE is a substance well known in mining districts, called *fluor*

*spar**. It is found crystallized in cubes of various colours, green, yellow, and purple; and a compact variety of the same substance, the product of Derbyshire, is worked into splendid ornamental vases. If this mineral be reduced to powder, mixed with twice its weight of strong hydro-sulphuric acid, and subjected to distillation, a powerful and highly corrosive liquid acid may be obtained. For this purpose a leaden or silver retort and receiver must be employed; and while a moderate heat is applied to the former, the latter must be kept cool by pounded ice or snow. The hydro-fluoric acid thus formed must be preserved in silver or leaden bottles, with stoppers of the same materials. It is extremely volatile, and not easily confined. In appearance it resembles oil of vitriol. Its specific gravity, when first prepared, is 1.06, but is increased by the gradual addition of water to 1.25; and there is no known instance of a similar condensation. It is necessary to use great caution in experimenting with this substance, as its vapours are highly irritating, and, when applied to the skin, it disorganises it so rapidly as to occasion dangerous ulcers. In addition to the usual properties of a powerful acid it acts strongly on glass, and corrodes it deeply. Plates of glass, covered with a composition of bees-wax and turpentine, may be drawn upon with a graver, and those parts which are laid bare may be perfectly etched by exposure either to the vapour or the diluted acid.

When brought into contact with potassium, a violent detonation takes place; *hydrogen gas escapes*, and a solid, white saline substance is formed, which may be called the *fluoride of potassium*, from analogy to the *chlorides*.

If lime be thrown into it, violent heat is extricated, water is given off, and the same substance as fluor spar or *fluoride of calcium* is produced. Attempts have been made to effect the decomposition of the fluoric acid, both upon the supposition that it may be a compound of an electro-positive body, such as sulphur, with oxygen; or that it is constituted of a highly electro-negative element, like chlorine, in union with hydrogen. The latter view is, of the two, the best supported by experiment and analogy.

When exposed to the agency of the voltaic pile, a disengagement of a small quantity of inflammable gas took place

at the negative pole while the wire of the opposite end became corroded, and covered with a chocolate-coloured powder, which has been supposed to be a compound of fluorine and platinum. It is argued that in this experiment the acid was decomposed; that the inflammable gas at the negative pole of the battery was hydrogen, and that the unknown element, upon its disengagement at the positive pole, immediately combined with the platinum. The result, however, cannot be considered as decisive, in as much as fluorine was not obtained in an insulated form; and from the noxious vapours which arose during the process, it was impossible to examine the products with that attention which the interest of the subject required. The highly active properties of this element throw peculiar difficulties in the way of its examination, as it attacks with great violence, as far as is at present known, all substances with which we are acquainted, and thus deprives us of the means of insulating and preserving it. A strong argument in favour of the elementary nature of fluorine is derived from the fact that fluor spar is not decomposed by the *anhydrous* sulphuric acid. (§ 118.) There being no water to furnish oxygen to the calcium, or hydrogen to the fluorine, the hydro-fluoric acid cannot be produced.

If the supposition that fluoric acid is a compound of fluorine and hydrogen be correct, the analysis of its compounds proves that the two elements are combined in the proportion of

1 equivalent fluorine	-	18
1 ditto hydrogen	-	1

and that its number must be

19

Fluosilicic Acid. ?

(§ 350.) WE have stated above, that fluoric acid acts upon glass in a very energetic manner; during this action it combines with the silic, of which it is composed, and assumes the gaseous form. This gas may easily be produced by pouring upon powdered fluor spar, mixed with half its weight of fine sand or glass, an equal weight of strong sulphuric acid. It may be collected over mercury, in glass jars, upon which it will no longer exercise any action. 100 cubic inches of it weigh 110.78 grains: it is colourless, and it affords, upon decomposition, 61 per cent. of silic. Its odour is penetrating, and its taste very

* So called from its assisting the fusion of earthy minerals in metallurgical operations.

sour. It extinguishes burning bodies, and produces white fumes when suffered to escape into the air.

Water absorbs about 263 times its volume of fluosilicic gas, and the solution may be kept in glass vessels. About 17 per cent. of the silica is precipitated during the absorption. The gas condenses twice its volume of ammonia, and forms with it a dry saline compound. It also combines with other bases. When pure potassium is burned in fluosilicic gas, it condenses it, and a brown substance is produced, which, after being boiled in water and dried, burns in oxygen gas. From the residue of the combustion, pure *silicon* may be obtained, by dissolving out some *silex* with which it is mixed by fluoric acid, and washing and drying the remainder upon a filter. This is the process to which we referred when treating of that element. (§ 176.)

Fluoboric Acid. 2

(§ 351.) If, instead of *silex*, fluor spar be mixed with half its weight of vitrified boracic acid (§ 184.), and 12 parts of strong sulphuric acid, and the mixture be gently heated in a glass retort; or if fluor spar, with boracic acid, be exposed to a strong heat in an iron tube, a gas may be collected in abundance over mercury which exhibits very peculiar properties. It is colourless, but possesses a very pungent odour, and instantly extinguishes flame. When it escapes into the air it occasions a dense white cloud, by combining with the aqueous vapour with which it is mixed. 100 cubic inches weigh 72 grains. It is rapidly absorbed by water, which takes up about 700 times its bulk; heat is given out, and the water increases in volume. The saturated solution is perfectly limpid, fumes when exposed to the air, and is very caustic. It acts with all the intensity of sulphuric acid upon organized substances, blackening and disintegrating them. It has no action upon glass. Potassium heated in fluoboric acid gas separates boron from it (§ 181.) in the form of an insoluble powder. It forms combinations with ammonia and other bases.

It is probable that both the fluosilicic and the fluoboric acids are binary compounds of fluorine; the former with silicon; the latter with boron; but the subject is as replete with difficulty as it is with interest; and although, in the present state of science, it affords one of the

most promising fields of investigation to the accomplished chemist, it will not advance our design to enlarge upon it on the present occasion.

CHAPTER XII.

On the Compounds of Cyanogen.

(§ 352.) WE have observed (§ 173.) that the *carburet of nitrogen*, to which the name of *cyanogen* has likewise been given, possesses the remarkable property of combining with elementary substances, in a manner perfectly analogous to that of the simple gaseous bodies: the mode of this combination and some of its most interesting results we shall proceed to examine.

When potassium is heated in cyanogen an energetic action ensues, the metal burns, and a saline body, the cyanuret of potassium, is generated. It also forms similar binary combinations with the other metals, the greater part of which, however, can only be obtained by the interchanges of a double decomposition. They are also perfectly neutral in their characters. (§ 26.)

Those compounds, however, which cyanogen forms with the non-metallic elements are of higher importance and interest, inasmuch as they are of an acid or electro-negative quality, and are capable of entering into combination with different salifiable bases.

CYANOGEN AND HYDROGEN.

Hydrocyanic or Prussic Acid. 27.

(1 C. 26 + 1 H. 1.)

(§ 353.) If a narrow tube be filled with fragments of the saline body called cyanuret of mercury (§ 172.), and placed in a horizontal position, when a stream of sulphuretted hydrogen gas is passed through it, a double decomposition ensues: the sulphur of the gas combines with the metal, black sulphuret of mercury is formed, and the cyanogen which is liberated enters into a new combination with the hydrogen. The product may be expelled by a very gentle heat, and collected in a receiver kept cool by ice. A similar product may be obtained by moistening the cyanuret of mercury with muriatic acid, and distilling at a low temperature. The hydrocyanic acid is a colourless liquid, possessing a strong odour resembling that of peach-blossoms. In its pure state it is intensely poisonous, and a single drop of it placed upon the tongue of a dog causes almost

instant death. When greatly diluted with water it has the taste of bitter almonds, which, in fact, owe their flavour to a small portion of this acid. Water distilled from the leaves of the laurel also derives its poisonous quality from the presence of the same ingredient. The vapour of the pure acid takes fire on the approach of flame, and when mixed with oxygen gas detonates with the electric spark. It is extremely volatile, and boils at 79° Fah.; and at 0° it congeals. When a drop of it is suffered to fall upon a piece of glass it becomes solid; the cold produced by its rapid evaporation being sufficient to freeze what remains. Hydrocyanic acid reddens litmus paper feebly, and forms salts with the different salifiable bases. Owing to the tendency of its component elements to form other arrangements, it is very liable to spontaneous decomposition, and it is not easy to preserve it from change even out of the contact of the air in well-stopped bottles. The diluted acid is sometimes used in medicine. If a quantity of potassium sufficient to absorb 50 measures of cyanogen be heated in 100 measures of the vapour of hydrocyanic acid, an absorption of 50 measures takes place, cyanuret of potassium is generated, and 50 measures of pure hydrogen remain; proving that it is composed of equal volumes of its two ingredients.

Its composition is therefore

1 equivalent cyanogen	26 =	$\begin{cases} 2 \text{ carbon } 12 \\ 1 \text{ nitrogen } 14 \end{cases}$
1 equivalent hydrogen	1	
and its combining	—	
proportion	- -	27
	—	

The specific gravity of the vapour agrees with this determination, having been found to be the mean of its two ingredients.

CYANOGEN AND OXYGEN.

Cyanous, Fulminic, and Cyanic Acids.

(§ 354.) MUCH uncertainty still exists with regard to the compounds of cyanogen with oxygen, and they are rather objects of further investigation than of elementary instruction. A compound of a peculiar acid, into the composition of which oxygen and the elements of cyanogen enter, and potash, may be obtained by the following means: expose to a low red heat equal weights of a salt called the anhydrous *ferrocyanate of potash* and peroxide of manganese: pulverise the resulting mass and boil it with pure

alcohol. On cooling the solution, a salt will be obtained in small crystalline plates. When a solution of this salt in water is merely heated, its acid is decomposed, and carbonic acid and ammonia are produced, and with greater certainty if a weak acid be added to the solution to assist in disengaging it from the potash. The result of an analysis founded on this property is, that it is composed of

1 equivalent cyanogen	-	26
1 ditto oxygen	-	8
		—
		34
		—

According to this analysis, the most appropriate name for this acid would be *cyanous acid*. It may be transferred from the potash by double decomposition to other bases, but, owing to the easy disunion of its elements, it has never been obtained in an insulated state.

(§ 355.) THE elements of the same acid united (probably) in the same proportions, but further necessarily combined with some metallic oxide, (as that of silver or mercury, and the nature of which appears to be in some degree indifferent,) constitute another acid or class of acids, to which the name of *fulminic* has been given. This acid, like the preceding, has never been obtained in a separate state; but united, besides the metallic oxide which constitutes one of its ingredients, with a further proportion of the same oxide, or some other, as a base. It may also be transferred to different bases by double decomposition. All the fulminates detonate violently by heat or percussion, and some of them with the slightest friction. Their properties will be further described amongst the saline compounds.

(§ 356.) ANOTHER acid of this class has lately been discovered, in which cyanogen is combined with a second equivalent of oxygen, and upon which the appellation of *cyanic acid* may with propriety be conferred. It may be obtained by the action of hot water upon the *perchloride of cyanogen*, (a substance presently to be described): muriatic acid and cyanic acid result from double decomposition; the former of which may be expelled by heat, and the latter obtained in a separate form. It may even be procured, it is said, in the form of crystals by careful evaporation. It forms a distinct class of salts with the different salifiable bases, and its analysis has shown it to be composed of

1 equivalent of cyanogen	26
2 ditto oxygen	16
making its number - -	42
	—

CYANOGEN AND CHLORINE.

Chlorocyanic Acid.—62.

(1 Ch. 36 + 1 Cy. 26.)

(§ 357.) If cyanuret of Mercury (§ 172.) be mixed with just sufficient water to reduce it to a semi-fluid state, and exposed to the action of gaseous chlorine, in the course of a few hours the colour of the chlorine will disappear, and a gas will be found in its place which is not absorbable by mercury, but instantly taken up by water. This is a true *cyanuret of chlorine* or the *chlorocyanic acid*. One portion of the chlorine, in this process, expels the cyanogen from the mercury, and forms bichloride of mercury, while another portion combines with the cyanogen, and forms the new compound. It possesses the remarkable property of crystallizing by a temperature of 0° Fah. (which may at any time be produced by mixing together pounded ice and common salt,) and may thus be separated from portions of other gases with which it would otherwise be liable to be contaminated. It becomes liquid about 8° or 10° Fah., and at 68° its pressure is equal to four atmospheres.

It constitutes an active poison, and is very caustic. It possesses a peculiar irritating odour; reddens blue vegetable colours, and does not explode when its vapour is mixed either with oxygen or hydrogen.

The constitution of chlorocyanic acid is probably

1 equivalent chlorine	-	36
1 ditto cyanogen	-	26
		—
		62
		—

Perchloride of Cyanogen.—98.

(2 Ch. 72 + 1 Cy. 26.)

(§ 358.) By pouring about 15.5 grains of pure *hydrocyanic acid* (§ 353.) into a bottle containing about 61 cubic inches of dry chlorine, closing the bottle with a stopper, and exposing it to the direct rays of the sun, the hydrocyanic acid is volatilized, and after a few hours a colourless liquid may be seen on the inner surface, which gradually thickens, and finally sets into a white substance, mixed with shining crystals. This is the *per-*

chloride of cyanogen. When dry and pure it is brilliantly white, and may be obtained in needles. Its vapour affects the eyes, and, after keeping, exhales an odour of muriatic acid. It fuses at 140° Fah., and boils at 190°. It is extremely poisonous; and is sparingly soluble in cold water, and decomposed by hot, as we have already explained. (§ 356.)

Its composition has been ascertained to be

1 equivalent cyanogen	-	26
2 ditto chlorine	-	72
		—
		98
		—

CYANOGEN WITH IODINE AND BROMINE.

(§ 359.) CYANOGEN forms binary compounds with iodine and bromine, analogous to the chlorocyanic acid, and whose properties resemble each other closely; it does not, however, consist with our purpose to enter upon their particular examination.

CYANOGEN AND SULPHUR.

Sulphocyanic Acid.

(§ 360.) A COMPOUND of cyanogen with sulphur may be obtained by the following means:—Mix together equal weights of *ferrocyanate of potash*, (a salt which is more commonly known by the name of *prussiate of potash*,) and flowers of sulphur. Melt the mixture in a flask, by a gentle heat, and keep it melted for several hours. When cold, reduce the mass to powder, and dissolve out every thing soluble by digestion with water. Filter the solution, and drop into it a solution of potash, as long as any precipitate occurs. The liquid thus obtained is then to be distilled with sulphuric acid. An acid liquor will collect in the receiver, which is the *sulphocyanic acid*. It is transparent and nearly colourless, possessing only a slightly pink hue. Its smell is pungent, and resembles that of acetic acid (strong vinegar). It may be obtained in crystals, at a temperature of about 55° Fah., and boils at 217°. When thrown into a red-hot platinum crucible, sulphur is disengaged, which burns with a blue flame. If brought into contact with ignited iron-turnings, sulphuret of iron is formed, and hydrocyanic acid and sulphuretted hydrogen are disengaged. It is probable, from its most careful analysis, that it is a *triple* compound of cyanogen sulphur and hydrogen, or

1 equivalent of cyanogen	-	26
2 ditto sulphur	-	32
1 ditto hydrogen	-	1

and that its number is - - 59

The necessary existence, however, of the hydrogen in this substance is at present disputed.

It reddens litmus paper, and is capable of uniting with the different salifiable bases.

CYANOGEN AND IRON.

Ferrocyanic Acid.

(§ 361.) BY adding the pigment called *Prussian blue* to a solution of barytes in water, till it ceases to be discoloured, and carefully evaporating the solution, crystals of a saline body may be obtained, which is called the *ferrocyanate of barytes*. If to a solution of this salt in water, sulphuric acid be carefully added till it ceases to form any precipitate, the liquid carefully decanted will consist of ferrocyanic acid, in which cyanogen is united with iron, and most probably with hydrogen, into an electro-negative compound. It has a pale yellow tint, possesses no smell, and permanently reddens litmus paper. It is decomposed by a gentle heat, or by exposure to a strong light, with the evolution of hydrocyanic acid; it cannot therefore be concentrated by evaporation or distillation in the common way. The same acid may however be obtained in crystals by the following process:—Dissolve crystals of tartaric acid in alcohol, and make a solution of ferrocyanate of potash in as little warm water as possible, in the proportion of 50 grains of the salt to 58 of the acid—mix the two liquids. An insoluble precipitate will be formed, and ferrocyanic acid will remain in solution in such a concentrated state, as to furnish yellow cubic crystals by spontaneous evaporation.

That the iron in this singular compound is a constituent element of the acid, and does not act the part of a base, is proved by the decomposition of one of its salts, the ferrocyanate of soda, by the electric pile. In this case, the iron passes with the other elements of the acid to the positive pole, whereas, if it existed as a base, it would be determined to the negative pole with the

soda. In confirmation of this fact it may also be stated, that in the saline bodies formed by this acid with the different salifiable bases, the most delicate tests fail to detect the presence of the metal, as it can no more be affected by them than the sulphur can be indicated by its proper tests when existing in the different sulphates.

From the best analysis it is probable that the ferrocyanic acid is composed as follows:—

2 equivalents hydrocyanic acid	54 =	$\left\{ \begin{array}{l} 2 \text{ equivalents cyanogen } 52 \\ 2 \text{ equivalents hydrogen } 2 \end{array} \right.$
1 equivalent cyanuret of iron	54 =	$\left\{ \begin{array}{l} 1 \text{ equivalent cyanogen } 26 \\ 1 \text{ equivalent iron } . . 28 \end{array} \right.$
		108 108

The subject, however, is still one of controversy, into which we do not deem it expedient to enter at present.

CHAPTER XIII.

On the Hydroacids and their Compounds: with General Remarks on Salts.

(§ 362.) IT now remains for us, in pursuance of our plan, to examine the results of chemical affinity between the compound electro-negative and electro-positive bodies which we have found to result from the combination of the non-metallic and metallic elements in very simple numbers and proportions; and to describe the more interesting of that numberless class of bodies formed by the union of acids and bases to which the name of salts has been given (§ 186). But before we proceed with this branch of our subject, we deem it expedient to make a few remarks upon a common property of one class of the foregoing acid compounds which may be distinguished from the general group—we allude to those, into the constitution of which hydrogen enters as the acidifying principle, and which may be designated as a class, by the name of *Hydroacids**. The following table will recal both their names and composition.

* See the note page 5

TABLE V.

HYDROACIDS.

	Equivalent.	Equivalent.	Equivalent.
Muriatic, or hydrochloric acid	37	1 Chlorine	+1 Hydrogen.
Hydrobromic acid	76	1 Bromine	+1 Hydrogen.
Hydriodic acid	123	1 Iodine	+1 Hydrogen.
Hydrofluoric acid	19	1 Fluorine	+1 Hydrogen.
Sulphuretted hydrogen	17	1 Sulphur	+1 Hydrogen.
Bisulphuretted hydrogen	33	2 Sulphur	+1 Hydrogen.
Hydrocyanic acid	27	1 Cyanogen	+1 Hydrogen.
Sulphocyanic acid	59	1 Cyanogen + 2 Sulphur	+1 Hydrogen?
Ferrocyanic acid	108	3 Cyanogen + 1 Iron	+ 2 Hydrogen?

It will be observed, that the *radicles* of these acids (a term equivalent to *Base*, but which is only applied to the acids: chlorine being the simple radicle of the muriatic acid, and cyanogen and iron the compound radicle of the ferrocyanic acid) are united with one equivalent of hydrogen, except in the last instance, which probably contains two equivalents. Now we have seen that three of these bodies, muriatic acid, hydriodic acid, and sulphuretted hydrogen unite with ammonia, and form distinct salts (§§ 189. 190. 193.) and all the others are capable of the same union, and form analogous saline compounds with the volatile alkali; but, when brought to act upon any of the bases which contain oxygen, a different series of phenomena takes place: they generally combine in exactly such proportions, as that the hydrogen which they contain may be sufficient to form water with the oxygen of the oxide. Thus, one equivalent of the protoxide of mercury will be taken up by one equivalent of muriatic acid; but one equivalent of the peroxide requires two equivalents of the same acid for its solution. Experiment proves that, in such cases, water actually is produced, and the metal forms a binary combination with the radicle. Thus, when we oblige dry muriatic acid to act upon potash or barytes, water is produced, and the resulting compound is precisely the same as when we directly combine potassium or barium with chlorine. Again, we have seen that, by burning sodium in chlorine (§ 321.), we obtain the well-known substance, common salt, which is a *chloride of sodium*: by neutralizing muriatic acid with soda, we obtain exactly the same product. While in solution, there is nothing to prevent our considering this as a true salt, or a *muriate of soda*: but when we oblige it to assume the solid form by the evaporation of its water, we know that it con-

tains neither oxygen nor hydrogen, and that it is a chloride of sodium. The converse of this proposition is also true, that any chloride dissolved in water may be regarded as the solution of the corresponding muriate, and, in some instances, we have demonstrative evidence that muriatic acid and an oxide are formed by the action of water upon a chloride. Thus, when chloride of antimony (§ 262.) is thrown into water, muriatic acid is produced, and a hydrated protoxide of mercury precipitated; as muriatic and sulphurous acids are generated by acting upon the chloride of sulphur by the same fluid (§ 126.). Nothing, on the other hand, prevents our conceiving the proper solution of a chloride, or of an iodide, in water, or obliges us to consider its nature altered by such solution. There is, it is true, something perplexing in the endeavour to follow this subject to its furthest consequences, but, after all, the difficulty is theoretical only, and it is perfectly indifferent whether we consider such compounds as chlorides or muriates, bromides or hydrobromates, cyanurets or hydrocyanates, &c. of the metals and their respective oxides; it being understood that these are only different ways of expressing the same phenomena. The least ambiguous examples of muriates of oxidated bases would seem to be those in which the compound, in crystallizing from its solution, carries with it a definite proportion of water, as water of crystallization: thus, muriatic acid will dissolve both the oxides of barium or strontium, and will afford crystals which differ from the respective chlorides by the water which they contain: these may, perhaps, be most properly called muriates; but, at the same time, it must be confessed that there is no very good reason for affirming, that the chlorides may not afford crystalline combinations, as such, with water.

Without giving too much importance

to these distinctions, we shall employ this double nomenclature, appropriate to the class of hydroacids, indifferently, as circumstances or facilities of explanation may seem to require. The different properties of the compounds depend solely upon the presence of the *radicle*, and are not affected by the elements of the water, in whatever way we imagine them to be combined; and we shall proceed to describe such of them as have not previously been examined with the binary compounds under the heads of their respective acids, in the general arrangement which we shall adopt of the saline bodies.

(§ 363.) We have before alluded generally to the mutual neutralization of acids and alkalis (§ 24.), and have explained the nature of salts, and the principles of the nomenclature by which they are distinguished (§§ 186, 196, 198.). It will be expedient to extend our general remarks upon this class of compounds previously to entering upon their individual characters.

It is a common mode of expression to speak of the solution of a metal in an acid; but without explanation this may be liable to misconception. No metallic body, as such, can be dissolved by an *oxyacid*: the action of the solvent is, first, to convert the simple element to an oxide, either by the decomposition of part of the acid itself, or of the water with which it is combined, and the salifiable base, thus formed, is afterwards taken up. This is even true of the *hydroacids*, whichever of the preceding views we may take of their combination; if we suppose that their radicles combine directly with the metals, it is still necessary that oxygen should be present to abstract their hydrogen: but if we imagine them to combine as acids, they can only unite with oxides. In some instances, indeed, the hydrogen of the acid itself is thrown off, but then the product is an undoubted binary compound, as *chloride*, *iodide*, &c. (§ 111.)

(§ 364.) In treating of the salts, it will facilitate our description to distinguish their physical from their chemical properties; by the former we understand the form, the colour, the taste, the smell, the density, fusibility, volatility, &c.; in the latter, we include the action of solvents, such as water, alcohol, and acids, and the effects of the various simple and compound bodies, as reagents. Some salts *decrepitate* when exposed to heat, that is to say, they fly

in pieces with a crackling noise, as common salt when thrown into the fire. This is owing to particles of water mechanically entangled in the act of crystallization, and which suddenly assumes an elastic form. Those salts which contain water, chemically combined, seldom decrepitate.

Some retain their water of crystallization by such a feeble affinity, that atmospheric temperatures are sufficient to expel it in a dry atmosphere. Their crystals then fall into a powder, and are said to *effloresce*. Others have such a strong attraction for water, that they absorb the aqueous vapour from the air and melt into solution, or *deliquesce*.

Many *anhydrous* salts may be melted by the application of strong heat without undergoing any decomposition; and this phenomenon is designated by the term *igneous fusion*; and many which contain water of crystallization, when exposed to an increased temperature, dissolve in that water: and this is called *aqueous fusion*. A salt may first undergo aqueous fusion, have its water all expelled by heat, and then become fluid under the igneous fusion. The action of water upon salts is of the utmost importance, as it includes the phenomena of solution and crystallization. The solvent power of this fluid is in general in proportion to its temperature; but there are, nevertheless, some exceptions to this general rule, as common salt, which is equally soluble in hot and in cold water. Some salts are wholly insoluble in water, as the sulphate of barytes; while others deliquesce so rapidly as scarcely to be preserved separate from it, as the muriate of lime. Alcohol is a solvent which acts upon a limited number of salts; but scarcely can be said to dissolve any but the deliquescent. From this property, it is often used to separate salts which are mingled together; acids, also, sometimes act merely as solvents, without producing any change in the constitution of the salt: thus, phosphate of lime, which is insoluble in water in any appreciable quantity, is readily taken up by muriatic or sulphuric acid.

(§ 365.) In general, however, when, upon a salt or a compound of an acid with a base, we pour another acid, the base must be considered as divided between the two. For example, suppose we take chloride of sodium, which, when dissolved in water, as we have seen, may be considered as muriate of soda,

and pour upon it some sulphuric acid, we shall have two acids, the muriatic and the sulphuric, which will divide the soda between them. The acid which we add being in excess, part of the other acid will be set free; and if it should be of a volatile nature, will escape; but if fixed, it will remain, and while it remains, it is easy to conceive that it will exert its attraction upon the base. So that the latter may be considered as divided between the two acids; each of the acids opposing the action of the other. Now, there are many acids which are not volatile, and there are some which, although volatile, may be considered as fixed at common temperatures, because they are always combined with water; and, whenever an acid is retained in a liquid so as not to escape into the atmosphere, it may be considered as fixed. In the example to which we have referred above, the muriatic acid which we have disengaged will fly off, because it is gaseous, unless we have previously dissolved the salt; but if we have taken this precaution, the muriatic acid gas will remain dissolved in the water, and should be considered as fixed. The sulphuric acid acts in the same manner in both cases; but in the latter, the decomposition will be less complete, because the two acids oppose each other: while in the former, the muriatic acid escaping, there is nothing to check the action of the sulphuric. Hence, we may conceive, that the affinity of the acids for the bases depends greatly upon their fixity, and that, under particular circumstances, a volatile acid may be considered fixed. In the experiment above, where the muriatic acid is retained by the water, if the solution be heated, the acid will be volatilized in conjunction with the water, and the sulphuric acid will regain the ascendancy and totally displace the muriatic. It is usual to explain this process by supposing that the muriatic acid has less affinity for the soda than the sulphuric, but it probably depends entirely upon the volatility of the former, at the temperature at which it is conducted.

Analogous phenomena attend the presence of different bases with an acid. If we take a salt in solution, and add another base, the acid will be divided between the two bases. Let us take chloride of barium for example: if we add to it caustic potash, the chlorine will be shared between the barium and the potassium: if one of these bases be less soluble than the other, a portion will be

set at liberty and precipitated; but if, before making the experiment, the solution of the chloride be greatly diluted, there will be no precipitate, because the whole will remain in solution.

Both these phenomena are of the same nature; the least soluble base corresponds to the volatile acid, and the precipitate to the disengagement of the gas. In one and the other case, a sufficient quantity of water can retain both bodies. Hence we may conclude, that when we pour a base into the solution of a salt, it will be that base which has least affinity for water, which will be disengaged. Thus, we shall find, that the soluble salts of lime are precipitated by barytes and strontian, and these again by potash and soda. The two bases divide the acid between them, when no disengagement or precipitate takes place. Again, when we mix together two different salts in solution, if by a mutual exchange of their acids and bases a salt can be formed of less solubility than those originally selected, double decomposition will certainly take place, and the less soluble salt will be precipitated, unless there should be sufficient of the liquid present to take it up. Hence we infer, that insolubility may determine the mutual decomposition and precipitation of salts. When solutions of sulphate of soda and nitrate of lime are mixed together, we may conceive that either acid would combine indifferently with either base; but sulphate of lime is formed, because, although a small quantity may at first be taken up by the water, it is insoluble in any considerable proportion in that liquid. It is thus that many cases of double elective affinity (§ 26.) may be explained, and if we are well acquainted with the relative solubility of the different salts, or their relative attraction for water, we may always anticipate the decompositions which will follow upon mixing their solutions. These phenomena are in strict accordance with the general principles which we expounded when speaking of the modifications which chemical affinity undergoes from the influence of cohesion, elasticity, and solution (§§ 28. 29. 31.). We shall avail ourselves in the sequel of opportunities of exemplifying the subject in detail.

(§ 366.) THE salts may, without a figure of speech, be said to be numberless; and, of course, vary greatly in importance, both with regard to their application, to the arts of life, and to the instruction which may be derived from their study

It is necessary for convenience, to divide them into groupes, and they may be arranged either in the order of the acids or in that of the bases. By the former method, all the salts which contain sulphuric acid would be classed together; by the latter, all those which contain potash, &c. We shall, for the present, adopt the first arrangement, and commence our examination with the general character of each groupe, and then proceed to the particulars of such individual salts as we may think it conducive to our purpose to describe.

CHAPTER XIV.

On the Nitrates and Hyponitrites.

(§ 367.) THE combinations of the nitric acid (§ 71.) with different bases, constitute a class of salts most important to the arts. When exposed to heat they are all decomposed, and the products are very various according to the nature of the base. If the attraction of the acid for the latter is but slight, it is given off without decomposition; but when stronger it is decomposed, and deutoxide of nitrogen, nitrogen, and oxygen, are evolved, according to circumstances. The different simple combustibles act variously, but with great energy upon the nitrates. At common temperatures they produce no effect, but when heated together different acids and oxides are formed. The nitric acid easily gives up its oxygen, which unites with the body thus presented to it. If we select nitrate of potash as an example, we shall find that with carbon it forms carbonic acid, and carbonate of potash will be the result; with phosphorus, phosphate of potash will be produced; and with arsenic, arseniate of potash. When the fixed acids are poured upon the nitrates they are decomposed, and nitric acid given off, and it is thus that nitric acid is procured for commerce, by distilling nitrate of potash with sulphuric acid (§ 72.).

The alteration which muriatic acid undergoes when brought in contact with the nitrates affords one of their most distinctive characters. In seeking to determine the nature of an unknown salt, if we mix it with a little muriatic acid and chlorine is given off in abundance, we may conclude that it is a nitrate. The hydrogen of the muriatic acid combines with the oxygen of the nitric acid, and both chlorine and coloured vapours of nitrous acid are disengaged. All the nitrates are soluble in water,

Nitrate of Potash.—102.

(1 N. 54 + 1 P. 48.)

(§ 368.) NITRATE of potash or nitre may be directly formed by neutralizing nitric acid with potash. It is composed of one equivalent of each of its ingredients. It crystallizes, in general, in six-sided prisms with striated surfaces; 100 parts of water at 32° dissolve 13.2 parts of the salt, but at 212° will take up 246.15 parts. It undergoes igneous fusion and becomes as liquid as water at a low red heat; it is sometimes cast into moulds and called *sal prunella*. At a white heat it is decomposed, and its acid resolved into nitrogen and oxygen. It undergoes no alteration in the air, but attracts moisture in a saturated atmosphere. Its taste is saline and cooling. The action of carbon upon nitre is very energetic, as may be seen by throwing a little upon lighted coals. The spots upon which it falls become instantly white hot. When a combustible body is mixed with nitre and gradually thrown into a heated crucible the process is called *deflagration*; it is employed when it is wished to unite different substances with oxygen. Sulphur treated in this way affords various products according to the proportion with which it is mixed. Equal parts of the two give rise to the formation of sulphate of potash, and oxygen is given off; two parts of sulphur and one of nitre occasion the formation of sulphurous acid in abundance; two parts of phosphorus and one of nitre yield a product of both phosphoric and phosphorous acids. All the metals may be oxygenated in this way, except gold, silver, platinum, and those rare substances which are found associated with the latter.

A mixture of three parts of nitre, two of carbonate of potash, and one of sulphur in powder, forms the *fulminating powder* which explodes with a loud noise when laid upon a metal plate heated below redness.

A mixture of five parts of nitre, one part of sulphur, and one of charcoal, finely powdered and very accurately blended, compose *gunpowder*. Great attention is paid in the manufacture of this important article to the purity of the ingredients: they are mixed together with great caution and pounded with wooden pestles with a sufficient quantity of water to prevent explosions. The mixture is granulated by passing through sieves, and carefully dried,

Nitre is found ready formed in nature ; and particularly in certain countries of the east in a kind of efflorescence upon the ground after the rains. It also forms upon old walls and buildings, and generally in places where saline bases, such as lime, potash, or soda abound, and come in contact with decayed animal substances. In France and Germany it is artificially produced by forming beds of such matters, but the consumption of this country is chiefly supplied from the East Indies.

Nitrate of Soda.—86. ?

(1 N. 54 + 1 S. 32.)

(§ 369.) WHEN nitric acid is saturated with soda, instead of potash, the product shoots into crystals of nearly a cubic form, instead of six-sided prisms. Their taste resembles that of nitre, but is more pungent.

The nitrate of soda is more soluble in cold water than the nitrate of potash, 100 parts of water at 32° taking up 73 parts; but boiling water does not dissolve more than 173 parts. The results of the decomposition of the two salts are nearly alike. The former is more deliquescent than the latter, and therefore not so well adapted to the manufacture of gunpowder, but it is sometimes used, as more economical, in the formation of fire-works. It is but little employed in the arts.

Nitrate of Ammonia.

(1 N. 54 + 1 A. 17 + 1 W. 9.)

(§ 370.) THE composition and chief properties of nitrate of ammonia have been described when treating of the ammoniacal salts (§§ 80. 188.). We shall only now allude to the great cold produced by the solution of its crystals in water. Water, at 55° Fah., upon being saturated with this salt, will have its temperature reduced to 9°, a reduction of 46 degrees. But what is most remarkable, if a solution at 9° be mixed with water at 55°, there will be a further production of 9° of cold, and the mean density of the two fluids will be greater after the mixture than before, affording an example of a reduction of temperature by condensation, which is an exception to the general law.

Nitrate of Barytes.—132. ?

(1 N. 54 + 1 B. 78.)

(§ 371.) THE nitrate of barytes may be prepared by dissolving the carbonate of barytes in nitric acid diluted with 8 or

10 parts of water. 100 parts of water, at 32°, will only dissolve 5 parts of this salt, but of boiling water 35 parts. It is perfectly insoluble in alcohol and nitric acid: if, therefore, we pour concentrated nitric acid upon carbonate of barytes, it will not be taken up, as the nitrate first formed cannot be dissolved. If strong nitric acid be poured into a solution of the salt in water, it will be precipitated. Nitrate of barytes decrepitates by heat, and is decomposed into nitrous acid and oxygen. When the nitrate is wholly decomposed the *peroxide* of barium is produced, which, however, is not quite so pure as when formed by passing oxygen over ignited barytes (§ 330.).

Nitrate of Lime.—82.

(1 N. 54 + 1 L. 28.)

(§ 372.) NITRATE of lime is composed of one equivalent of nitric acid and one of lime. It forms crystals resembling bundles of needles diverging from a common centre. It rapidly dissolves in water, and is deliquescent. Alcohol also takes it up in abundance, and it may thus be separated from nitre, with which it is generally found mixed as a native production. It is very readily decomposed by heat, and yields nitrous acid in great quantities. The crystals contain a considerable quantity of water of crystallization, the amount of which has not been ascertained. When nitrate of lime has been kept fused for about ten minutes in a crucible, and then poured into an iron vessel previously heated, the congregated mass broken in pieces and exposed in a well-stopped bottle to the light of the sun for a few hours, will emit in the dark a beautiful white light. This preparation has been called *Baldwin's phosphorus*.

Nitrate of Copper.—188.

(2 N. 108 + 1 C. 80.)

(§ 373.) COPPER readily dissolves in nitric acid diluted with two or three parts of water to temper its action, which otherwise would be violent and dangerous. The metal becomes oxidated at the expense of a portion of the acid, deutoxide of nitrogen is given off in abundance, and the peroxide is dissolved by the remainder (§ 363.). Two equivalents of the acid thus combine with one of the oxide, and a large proportion of water, amounting to 14 equivalents. It ought strictly to be called the binitrate of copper. It forms crystals of a splendid blue colour, but the anhydrous salt is white. When

these crystals are coarsely pounded, sprinkled with a little water, and quickly rolled up in tin-foil, there is much heat produced, nitrous gas is rapidly evolved, and the metal generally takes fire. The salt is caustic, and corrodes the skin; its taste insupportably styptic. It is very soluble in water, and is even taken up by alcohol. By adding a small portion of potash or ammonia to its solution, or by greatly heating the dry salt, a *subnitrate* of copper is formed in which the acid exists in much smaller proportion to the acid. By heating the nitrate to redness, pure peroxide of copper may be obtained.

Nitrate of Lead.—166.

(1 N. 54 + 1 L. 112.)

(§ 374.) NITRIC acid a little diluted dissolves lead with the extrication of deutoxide of nitrogen, or the same salt may be formed by digesting litharge (§ 232.) in the diluted acid. It crystallizes in white, opaque octohedrons which contain no water of crystallization. Their taste is sweet, like that of all the salts of lead. They are composed of one equivalent of both acid and base. The nitrate of lead is not very soluble, as 100 parts of cold water will only take up about 13 parts of the salt. When exposed to heat it decrepitates, then melts and gives off nitrous acid and oxygen. When distilled from a glass retort, the product condensed in a receiver, kept cool for the purpose, is a yellow liquid, which is said to be pure anhydrous *nitrous acid* (§ 69.).

A solution of nitrate of lead may be partially decomposed by ammonia, so as to form several *subnitrates*. On adding a very small quantity of the alkali a subnitrate is formed, composed of 1 equivalent of acid, and 2 of the base; a little more produces a compound of 1 equivalent of acid and 3 of base, and an excess of ammonia precipitates a salt composed of 1 of acid and 6 of base.

Protonitrate of Mercury.—262.

(1 N. 54 + 1 M. 208.)

(§ 375.) It will be recollected that mercury forms two oxides, which constitute salifiable bases (§ 203.): the nitric acid is capable of combining with both.

(§ 376.) THE chemical nomenclature distinguishes such salts by transferring to the acid the Greek numeral, or preposition, which is used to designate the oxide (§ 55.). Thus the salt which the nitric

acid forms with the *prot*-oxide of mercury, is called the *proto*-nitrate of mercury; while that with the *per*-oxide is termed the *per*-nitrate (§ 376.). The protonitrate of mercury may be formed by digesting mercury, at a low temperature, in nitric acid, diluted with three or four parts of water, until the acid is saturated; and then, allowing the solution to evaporate spontaneously, a small quantity of deutoxide of nitrogen is slowly given off during the process. A little of the metal should be left in the liquid to prevent the formation of a proportion of the pernitrate. The protonitrate may also be procured by boiling a solution of the pernitrate with an additional quantity of mercury. The newly added metal will become oxidated, at the expense of that already dissolved, and will be taken up by the acid. This salt may be wholly dissolved by water, slightly acidulated with nitric acid, but pure water has the property of precipitating from this and other mercurial salts, sub-salts of various composition.

The crystals of protonitrate of mercury contain water, probably to the amount of two equivalents.

Pernitrate of Mercury.—486.

(1 N. 54 + 2 M. 432.)

(§ 377.) WHEN mercury is heated in an excess of strong nitric acid, it is dissolved with a brisk effervescence of deutoxide of nitrogen, and transparent prismatic crystals are deposited as the solution cools. This salt is composed of one equivalent of acid, and two of the base. If the solution be poured into cold water, a white precipitate is formed; or, if into boiling water, an orange-coloured one, consisting of nitric acid, with a great excess of oxide, and forming an insoluble *sub-pernitrate*.

We have stated (§ 203.) that the *pernitrate* of mercury may be decomposed by heat, and that the peroxide will remain. It is more correct to say, that the oxide so obtained still contains a small proportion of acid, and is therefore not so pure as when formed by heating the metal with access of air.

Nitrate of Silver.—172.

(1 N. 54 + 1 S. 118.)

(§ 378.) THE nitric acid readily acts upon silver, and dissolves it with a copious disengagement of the deutoxide of nitrogen. When the metal is pure, the solution is colourless, contains a

slight excess of acid, and forms, by spontaneous evaporation, large regular crystals of the form of flat rhombs. This salt is composed of one equivalent of acid and one of base, and contains no water of crystallization. Water will dissolve of it about its own weight, at the ordinary temperature of the air, and alcohol about a quarter of its weight. The crystals of nitrate of silver fuse at a temperature under a moderate heat, and being poured into heated moulds, form the *lunar caustic* so much used in surgery.

A solution of this salt stains animal or vegetable substances of a deep black colour, after exposure to light. This seems to arise from a reduction of the oxide to the metallic state; for ivory, which has been so stained, will, when burnished, exhibit a bright metallic surface, resembling that of pure silver. This property is turned to account for marking linen, &c., in a permanent manner. For this purpose the cloth is moistened with a liquid made by dissolving two ounces of subcarbonate of soda and two drachms of gum-arabic in four ounces of water, and the solution of the salt itself thickened with a little gum, and coloured with Indian ink. The nitrate of silver is easily decomposed by a multitude of bodies. If it be mixed with a little carbon, and exposed to the temperature of boiling water, deutoxide of nitrogen and carbonic acid are evolved, and the silver is obtained in crystals. When mixed with phosphorus, and smartly struck with a hammer, the decomposition takes place with detonation; and if a stick of phosphorus be left immersed in its solution, it will become beautifully silvered. Most of the metals decompose it, and take its place with the acid. If a little mercury be poured into a bottle filled with a solution of the salt, after a little while the silver will be precipitated, of a beautiful form, resembling the branches of a tree, which has been called the *Tree of Diana*.

When the solution is contaminated (as often occurs) with copper, it may be purified from the latter metal by precipitating a portion of it with excess of potash. The precipitate will consist of a mixture of the oxides of silver and copper. This, when well washed, may be thrown into the remainder of the solution; and the oxide of silver having a greater affinity for the acid than the oxide of copper, the former will displace the latter, which will be precipitated.

THE HYPONITRITES.

(§ 379.) It will be remembered that there are two acids formed by nitrogen, of minor degrees of oxygenation than the nitric: namely, the nitrous and the hyponitrous (§§ 68. 69.), but the latter only affords salts with the different bases; as, when the former is made to act upon them, protoxide of nitrogen is disengaged and a hyponitrite formed.

The hyponitrites may be distinguished as a class by the red vapours which they emit when acted upon by other acids, such as weak sulphuric or nitric, or even acetic acids. The hyponitrous acid is thus decomposed into nitrous acid and nitrogen. Muriatic acid is not decomposed by them, nor chlorine evolved, as by the nitrates (§ 367.). When exposed, with different combustibles, to the action of heat, they are decomposed, in an analogous manner to the nitrates, but with much less energy. When their solutions, diluted with water, are boiled, they are decomposed, subnitrates are formed, and nitrogen disengaged.

Hyponitrites of Lead.

(§ 380.) If we take 100 parts of nitrate of lead in crystals and 78 parts of lead in a state of fine division, and heat the mixture so as to make it boil, we shall obtain a salt, which, on cooling, will crystallize in beautiful gold-coloured needles. It may be considered as a subhyponitrite of lead, being composed of two equivalents of oxide of lead, and one of hyponitrous acid. It is but slightly soluble in water, and acts upon vegetable colours as an alkali.

If carbonic acid be passed into its solution, half the lead will be precipitated as a carbonate of lead, and a neutral hyponitrite of lead (that is to say, a salt composed of one equivalent of each of its ingredients) will be left in solution. A small quantity of sulphuric acid will also precipitate half the lead.

By adding a larger quantity of lead to the nitrate of lead, a yellow liquid will be obtained, which, upon evaporation, will yield octohedral crystals, resembling that of the nitrate itself, except in being yellow. This is another subhyponitrite, consisting of 3 equivalents of base: and lastly, by boiling together 2 parts of nitrate, 3 of lead, and 100 of water, until the whole is taken up, a brick-red salt will be obtained, composed of 4 equivalents of base. This salt contains

a proportion of water, but is less soluble than the others.

Hyponitrites of Copper, &c.

(§ 381.) THE hyponitrite of copper may be formed, by carefully pouring into a solution of sulphate of copper some hyponitrite of lead. A double exchange will take place, sulphate of lead will be precipitated, and hyponitrite of copper remain in solution.

Hyponitrite of iron and other hyponitrites may be formed by similar operations: but they have been little studied, and have not been applied to any practical purpose.

A hyponitrite of potash is probably formed, when nitrate of potash has been exposed to a moderate red heat, for if acetic acid be found upon the residue, it emits red fumes, whereas, before the application of the heat, the salt is not at all affected.

CHAPTER XV.

On the Chlorates, Perchlorates, and Combinations of Chlorine with Oxides.

(§ 382.) THE chlorates resemble the nitrates very much in general characters, and they are easily characterized as a class. The chloric acid contains the same number of equivalents of oxygen as the nitric (§ 92.), but still more loosely combined; so that its salts are decomposed with extreme facility, either by mere heat or by combustible bodies. They give off pure oxygen when exposed to a high temperature, and deflagrate readily when thrown upon ignited coals. When treated with sulphur, they form large quantities of sulphurous and sulphuric acids, and when treated with muriatic acid they yield chlorine and its protoxide. The sulphuric acid disengages from them peroxide of chlorine (§ 98.). With sulphur and phosphorus they detonate violently by percussion. They are never found as natural productions.

Chlorate of Potash.—124.

(1 C. 76 + 1 P. 48.)

(§ 383.) THE chlorate of potash may be formed by the direct combination of the acid and the base, or by passing chlorine into a concentrated solution of pure potash, until the latter is completely neutralized. The solution obtained by the last process, after being boiled for a few minutes, will contain both muriate and chlorate of potash. If gently evapo-

rated, till a pellicle forms upon its surface, and suffered to cool, the chlorate will crystallize, and the muriate remain in solution. The chlorate of potash is perfectly anhydrous, and composed of one equivalent of acid and one of base. It is obtained crystallized in small scales, whose regular form is rhomboidal. Its taste much resembles that of nitre. It is but little soluble in cold water, but much more so in hot. It may be fused by a strong heat without decomposition; but upon increasing the temperature still further, it gives off 6 equivalents of oxygen, and chloride of potassium remains (§ 36.). It explodes violently by percussion, or trituration in a mortar, when mixed with sulphur or carbon; with phosphorus the experiment is dangerous, from the violence of the effects.

When thrown into concentrated sulphuric acid, enough heat is disengaged to inflame combustible bodies—such as sulphur and resins. It is to this property that the *instantaneous-light matches* owe their efficacy: three parts of chlorate of potash are mixed with one part of sulphur or sugar, and made into a paste with a little thick gum-water. The matches are dipped into the mixture, and when touched with sulphuric acid they instantly burst into flame.

Attempts have been made upon a large scale to manufacture gunpowder with this salt, instead of nitre; but so many serious accidents occurred from spontaneous explosions, that the attempt has been abandoned. Mixtures of it with different combustibles have been also applied for percussion priming to guns, but it was found seriously to act upon the barrels, and it has been abandoned for the fulminate of mercury, which has no corrosive property.

Chlorate of Soda.—103.

(1 C. 76, + 1 S. 32.)

(§ 384.) THE chlorate of soda is best prepared by the direct combination of the acid and the base: it may also be procured by the same process as the chlorate of potash, substituting soda for potash; but it is much more soluble than that salt in cold water, and therefore not so easily separable from the chloride of sodium with which it is mixed. It also assumes the cubic form in crystallizing; and is scarcely to be distinguished by the taste from the chloride. Its properties agree with those of the chlorate of potash.

(§ 385.) It may be well to mention

here, that when experiments are to be made upon the decomposition of substances which explode by heat, it is best to mix them with a large proportion of some inert substance in powder, such as sand, sulphate of potash, &c. Thus mechanically diluted, as it were, they only gradually receive the impression of the heat, in very small portions at a time; and, by adopting this precaution, the most explosive powders may be safely analyzed, and their gaseous products accurately collected.

Chlorate of Barytes.—154.

(1 C. 76 + 1 B. 78.)

(§ 386.) WE shall describe one more of the chlorates, on account of the interest which attaches to it, from being the source whence the chloric acid is obtained (§ 92.). The fluosilicic acid (§ 350.) has the property of forming a salt with potash, which is insoluble at the ordinary temperature of the air. By mixing this acid in excess with a solution of chlorate of potash, an insoluble precipitate is formed with the alkaline base, which, at first, is of a gelatinous form, and scarcely visible, but afterwards becomes very dense: this must be separated by the filter. A solution of barytes in water, also in excess, is mixed with the clear liquid; and a current of carbonic acid is passed through it, which precipitates the excess of barytes in an insoluble form. It crystallizes in four-sided prisms; and 100 parts of water, at ordinary temperatures, will dissolve about 12 parts.

PERCHLORATES.

(§ 387.) THIS class of salts, and the acid of which they are composed (§ 94.), are but little known. They act with great violence upon ignited coal, on account of the great excess of oxygen which enters into their composition, and of which they possess two equivalents more than the chlorates. They are readily decomposed by heat and by all combustible bodies. The acid enters into combination with all the bases, and the products are perfectly neutral, (*i. e.* possess neither acid nor alkaline properties.)

Perchlorate of Potash.—148.?

(1 C. 100 + 1 P. 48.)

(§ 388.) THE perchlorate of potash may be obtained by gently heating, to the temperature of about 116° Fah., a mixture of one part of chlorate of potash with two

of sulphuric acid. Peroxide of chlorine (§ 390.) is given off during the process, and a mixture of this salt with bisulphate of potash remains. The latter, being more soluble than the former, may be separated from it by washing, and by careful crystallization the perchlorate may be collected in small octohedral crystals.

It is quite insoluble in alcohol, and requires fifty-five times its weight of water at 60° for its solution: it, however, dissolves much more freely in water of 212°. It is from this salt that perchloric acid has been obtained, by distilling it with an equal weight of sulphuric acid at a temperature of 280° Fah. When exposed alone to a temperature of 412° Fah. it is converted into chloride of potassium and oxygen gas.

COMBINATIONS OF CHLORINE WITH THE OXIDES.

(§ 389.) UNCOMBINED chlorine is also capable of uniting directly with potash, soda, lime, and, probably, other oxides. The compounds have but little stability, and must be carefully distinguished from those of the corresponding metals, or the chlorides of potassium, sodium, calcium, &c. The two first, which can only be obtained in the liquid form by passing a current of chlorine through solutions of the two alkalies, are speedily converted into mixtures of chlorates of potash or soda, and chlorides of potassium or sodium. They all possess powerful bleaching properties, and emit a faint smell of chlorine.

Chloride of Lime.

(§ 390.) THE manufacture of chloride of lime (commonly called *bleaching powder*) is of great importance, and is carried on upon a very large scale. It is prepared by passing chlorine into chambers constructed for the purpose, in which strata of fresh slaked lime, in fine powder, is exposed to its action in trays. The gas is absorbed with rapidity, and much heat is evolved. It is necessary, indeed, to regulate this last circumstance by passing the current of gas very slowly into the apparatus, or by surrounding it with cold water; as a too high temperature determines the formation of a large proportion of chlorate of lime.

The chloride of lime is thus obtained in the form of a dry, white powder, which possesses a faint odour of chlorine, and a strong penetrating taste. When agitated with water, a portion is dissolved, which varies in different specimens. Its exact composition is a matter of contro-

versy; but it is probable that the dry powder consists of one equivalent of chlorine united with two of hydrate of lime, and that, when dissolved, one equivalent of the latter is precipitated; and that the chloride which remains in solution is composed of one equivalent of chlorine and one of the hydrate. When fresh prepared, with care, it does not contain any admixture of muriate of lime (*chloride of calcium*); but by long keeping, especially if moist, this salt is produced.

When exposed to heat, it is decomposed; a small quantity of chlorine and water are first given off, and, upon raising the temperature to 600°, the oxygen of the base is evolved, and chloride of calcium produced. The chlorine is also readily displaced by the different acids, even by the carbonic, whose affinities are probably the weakest of all.

It is very extensively used in bleaching, as it destroys colours nearly as efficaciously as chlorine itself. Its power for this purpose, and consequently its commercial value, may be estimated by its action upon a solution of indigo of known strength. When a solution of the chloride is exposed to the air, the carbonic acid gradually displaces the chlorine, which slowly escapes into the atmosphere, and carbonate of lime is produced. Advantage has been taken of this property for a most beneficial purpose, and one which cannot be too widely published, or too urgently enforced, by all those who may have it in their power to recommend it by precept or authority. Gaseous chlorine possesses the power of destroying the volatile principles given off by bodies in a state of putrefaction or infectious effluvia, and is often used with great advantage for the purposes of fumigation; but its smell is of such a suffocating nature, and so irritating to the lungs, that the greatest caution must be taken not to inhale it in any quantity. In the process, however, above described, it is so gradually evolved as not to occasion inconvenience; and it may be thus exposed, even in the chambers of the sick, without the slightest annoyance. Unpleasant exhalations are instantly neutralized by this salutary process, contagion checked, and a pleasant freshness communicated to the air, which does not merely cover disagreeable smells, like common fumigations, but effectually destroys them. The chloride is cheap and easily procured; and the quantity of a table-spoonful, stirred into as much water as may be

contained in a soup-plate, and renewed every two or three days, is quite sufficient in all ordinary cases. During fevers of a decidedly infectious character, the solution should be sprinkled about the chamber, and the linen of the patient thrown into a pail of water in which double the above quantity of the salt has been mixed. There is reason to believe, from actual experiment, that the contagion of the plague itself may be stopped by these precautions. The full benefit of the discovery, however, can only be derived from the people acting for themselves in this matter, and not waiting for the recommendation of medical men, who, from their constant attendance upon disease, are possibly less alive to the dangers which surround them; and, except in very decided instances of infection, may sometimes be unfortunately afraid of the ridicule of giving way to unfounded alarm. The precaution is neither expensive, troublesome, nor unpleasant, and is perfectly within the reach of the poorest of the community. In no case can it be productive of any injurious effects; and he who is acquainted with the facts, is guilty of the grossest negligence who does not have recourse to such simple means of prevention, even in cases of the very slightest suspicion. We are well aware that we are exposing ourselves to some ridicule for so strongly enforcing such a subject in a scientific treatise; but when we consider that these pages are destined for thousands to whom other sources of such information are not accessible, we should feel ourselves guilty of the same kind of negligence which we strongly condemn in others, if we did not avail ourselves of the opportunity of widely extending the useful knowledge of the disinfecting power of the *bleaching powder*, or chloride of lime.

CHAPTER XVI.

On the Murates and Chlorides.

(§ 391.) REFERRING to the general observations which we have just made, (§ 362.) upon the nature of the compounds of the *hydroacids*, we propose in this chapter to treat of the products of the action of the muriatic acid upon the different bases, and to describe their properties, whether as murates or chlorides, with more particularity than it consisted with our purpose to do under the binary compounds. One of the distinctive characters of this class of salts, is their inalterability with the

THE ART OF BREWING.

CHAPTER I.

Introductory.

THE artificial formation of exhilarating and intoxicating liquors has been practised in most ages and nations. Wine, which is prepared from the juice of the grape, is mentioned in the earliest records of history. The Tartar tribes, from time immemorial, manufactured their *kumis* from the milk of the mare and of the cow: the *chiaca* of the East Indies is the produce of rice: the Mexicans, before the arrival of the Spaniards, had different kinds of cheering liquors; from the *metl*, or *magnai*, a species of aloe (*Agave Mexicana*); from certain palms and from maize: and the Germans, in the time of Tacitus, brewed *zythum* and *curmi* from barley, in the manner in which we make our ALE and BEER.

All these preparations, and numerous others which we have not named, have certain properties in common. They constitute a genus, under the denomination of *Vinous Liquors*, because that of the vine is pre-eminent. They all acquire their inebriating quality from a similar fermentation; and all give out fluids by distillation, in which that quality is concentrated in a far less bulk. These latter fluids are called, generally, *Spirits*, or *Spirituuous Liquors*; and have the specific names, *Brandy*, *Ariki*, *Arrack*, *Whisky*, &c. each differing from the others in flavour, according to the material from which it is drawn. They are all, however, convertible, by subsequent distillation, into the same sort of liquid, which is termed *Spirit of Wine*, or *Alcohol*. There are thus three stages or three processes: the fermentation which produces wine, beer, &c.; the distillation of these fermented liquors, producing spirits; and the distillation of spirit, producing alcohol.

Although we were able, it is not our present business to describe the various processes by which vinous liquors may be prepared from different substances. What we here undertake is to treat of the Vinification of Barley; and, when we shall have, occasionally, to speak of the fermentation of other vegetables, it will be solely for the purpose of eluci-

dation. The comparison of Ale with Wine will be frequent; but for the particular processes, by which the latter and its numerous imitations are produced and preserved, we must refer to the TREATISE ON WINE-MAKING.

Though Brewing is certainly a chemical art, it has hitherto derived little, if any, advantage from the science of chemistry. In fact, nothing is to be expected from that quarter. Of all material substances, vegetables are the most difficult to analyze. Their *immediate materials* (as the results are termed) are often *produced*, rather than *found*, in the laboratory. The acids are connected by an invisible chain. The *fecula*, or *starch*, becomes *gum*, or *sugar*, by almost imperceptible processes. The seeds of plants are endowed with a vegetable life, which is absolutely necessary to vinous fermentation. A vivifying power shall exist when the grain is cut to atoms, which an unlucky twist of the mill might have utterly destroyed. Our chemists are men of the closet; and the manufacturer who operates on three hundred quarters of grain at a time can hope for little information from general theories, although upheld by the analyses of twenty barleycorns and their infusions in a quart bottle.

While the art of Brewing has been so little indebted to the progress of chemical knowledge, it has been considerably retarded by a power to which it had a right to look for assistance,—the Legislature of the country. The public Brewer, from whom only the art could receive improvement, is completely fettered by the laws of excise. The French *Vigneron* may flavour his wines at pleasure; and, by means of extraneous substances, may prevent or cure their degenerations; but malt, hops, water, and isinglass are the only materials of the British Brewer. Under whatever circumstances, everything else is inexorably prohibited. There is no distinction between useful and poisonous ingredients: all are stigmatized as illegal; and the penalty is the same for a single eggshell as for a pound of opium.

In addition to these absurd prohibitions, the public brewer has to struggle under a direct impost, amounting, in

most cases, to 50th per cent. on the first cost of his materials, and from which the private brewer is wholly free. The duties upon ale and beer brewed for sale, which were first imposed in 1643, have been increased, from time to time, until they have reached their present enormous amount. We shall not stop to trace their progress, but we may remark that, at a certain period, in distinguishing between small beer and strong, all ale or beer, sold at or above ten shillings per barrel, was reckoned to be *strong*, and was, therefore, subjected to a higher duty. The cask which contained this strong beer was then first marked with an X, signifying *ten*; and hence the present quack-like denominations of XX (double X), and XXX (treble X), which appear, unnecessarily, on the casks and in the accounts of the strong-ale brewers. A curious change of circumstances has rendered this letter still an appropriate mark in the books of excise. Ten shillings has no longer any relation to the *selling price*, but it is now the *duty* per barrel.

But it is not of the amount alone, but of the proportions in which the duty is levied, that the brewers, as well as their customers, have occasion to complain. Small beer is charged only at the rate of two shillings the barrel; and by small beer is understood all ale or beer that is sold to the customer at, or under, the price of twenty-four shillings. All that is sold above this price is accounted strong, and is liable to the ten shillings duty. The strength of the beer, which ought to be the criterion, is here out of the question; for, if any gentleman were to go to his ale brewer, and say that he wanted an article better than small beer, for which he would pay eight or ten shillings more, the brewer could not furnish it, because, if he charged more than twenty-four shillings per barrel, he would have to pay the ten shillings duty, so that he could not give a better article for thirty-two shillings a barrel than for twenty-four. A cheap table ale is nevertheless much in demand, and is often furnished at forty shillings, or less. The temptation to evade the strong ale duty is great, and, consequently, as appears from the numerous convictions, the mixing of strong beer with small beer is not uncommon. Were the duty, by some means, proportioned to the strength, this would seldom be done. But we should write a volume were we to detail all the frauds and inconveniences con-

sequent upon the absurdities of the present brewery laws. In small works, unless the brewer will consent to adopt the measures of those whose consciences are not too confined, he will seldom succeed in his business.

It may be thought that we have dwelt too long on this subject, but we shall have frequent occasions to show that the laws of excise must undergo some change before the art of brewing can be much advanced, without involving the trade in total ruin. It is now preserved in consequence of the ignorance, or the indolence, of the servants in private families. The tax on public brewers is beyond all ordinary bounds. Were a penny a quartern loaf levied upon the bakers, their ovens would soon be cold; and yet we consent to pay *twopence* upon every pot of porter which we drink. In proof, the following is a statement of the expense at which any private gentleman, who understands the manipulations, might brew porter of as good a quality as any that is usually sold in London:—

	Shillings.
1 Quarter of Malt, at 65s. per quar.	= 65
3 Quarters of Barley, at 40s. per quar.	= 120
32 lbs. of Hops, at 112s. per cwt.	= 32
Colouring, either from patent Malt or burnt Sugar	} 5

Cost of Materials . . . 222

To this there is nothing to add but the labour which, to those who keep men-servants, costs nothing. The grains and yeast may be considered as an indemnification for the coals. If the brewing were properly managed, it would produce fifteen barrels of porter, of the average London strength, at a price under *fifteen shillings* a barrel, or *five farthings* a pot. This calculation was made in 1827, and the value would, of course, vary with the alteration of prices, but the sketch here given is sufficient to prove that, under the present laws, were the art of brewing generally understood, the trade of a public brewer could exist only upon the earnings of the poor; for all who could muster a few pounds would brew for themselves. We have supposed *raw grain*, not so much on account of the saving of malt-duty as of its making a *better* beverage; but even were the porter made wholly of malt the saving would be enormous. Thus:

	Shillings.
4 Quarters of Malt, at 65s. per quar.	= 260
32 lbs. of Hops, at 112s. per cwt.	= 32
Colouring	. . . 5

These materials would produce fifteen barrels of good porter, at less than 20s. per barrel, which is little more than three-halfpence the pot.

CHAPTER II.

Of Brewing Utensils.

ALTHOUGH the names and general use of the principal brewing utensils are almost universally known, yet a few remarks, upon their construction, may be of advantage to those who have not had experience in their erection.

§ 1.—*Of Grinding Machines.*

Malt is prepared for the mash-tun in two different ways,—by *crushing*, or by *grinding*. In the former case the malt is made to pass between two cylindric rollers, close enough to burst the skin and bruise the kernel. This answers the purpose very well with regard to good malt; but when we have occasion to make use of raw grain, or of grain that has not been sufficiently malted, there is a certain loss of materials which would be secured by *grinding*. The cause of this loss will appear afterwards, when we treat of the means of producing a saccharine extract.

Grinding is best performed by mill-stones cut sharp for the purpose. Private families cannot generally afford the expense of mill-stones, which, besides, are not now erected, like the querns of our ancestors, so as to be turned by a man. In the neighbourhood of corn-mills, the miller could do this duty; but his multure is seldom determinate. A *steel-mill* is the best succedaneum. It may be had of any size, and, consequently, at various prices, from three to ten guineas; and, we believe, there is no law to prevent a machine of this kind from serving a whole neighbourhood, unless it may be in special cases of *thirlage*.

By whatever machine the barley, or malt, is ground, it ought to be cut sharp and small; especially the former, which must on no account be powdered into dust, but cut into particles like sand or well-ground oatmeal; and, for this purpose, if not already hard, it must be dried on a kiln. Those who use small quantities may purchase the barley in that state, but licensed brewers, be it remembered, must not use it at all. The malt needs not to be ground so fine. Neither should it be kept above a day or two in a ground state, because all

sorts of meal are apt to heat by reason of a fermentation that would terminate in putridity. We have known it clotted so hard that it required to be broken by a mallet; and the flavour, in consequence, was spoiled.

§ 2.—*Liquor and Wort Coppers, and Underback.*

Water, in the language of the brew-house, is termed *Liquor*; the cut (or bruised) malt, or grain, is *Grist*; when put into the mash-tun it is called the *Goods*; and the extract made from these goods, by infusion in hot liquor, is termed *Wort*. The liquor-copper, then, is a boiler chiefly used in heating water, for the purpose of infusing the goods in the mash-tun, or for supplying any part of the brewhouse where hot water is required; and the wort-copper is that in which the worts are boiled, along with the hops, for the purpose of giving bitterness, flavour, and (as is generally believed) a preservative quality. In small works, and particularly in private families, one boiler is made to answer the double purpose of a liquor and a wort copper; but this is done always at some loss, and frequently at the risk of destruction to the whole brewing. When the FIRST MASH (or infusion) is ready to be drained, it must be drained into a vessel called an UNDERBACK, because the copper is not ready to receive it; being employed in heating liquor for the second mash. The same happens in the third and fourth mashes, if there are so many; and the wort, thus remaining so long in the underback, gradually becomes tepid, generally contracts a disagreeable flavour, and often turns into that peculiar state of acidity which the brewers designate by the denomination of BLINKED. This last evil, however, (which admits of no remedy) is sometimes occasioned by improper heats in the mash-tun; but there the accident is more easily guarded against, because it never occurs unless the heat of the mashing liquor has either been too low, or has been allowed to stand too long upon the goods. If the last runnings of the mash be free from any tincture of acidity, and if they can then be immediately carried to the copper and submitted to heat, the mishap of *blinking* will always be prevented; and this, by the assistance of two coppers, can be readily accomplished.

The expense of two coppers in place

of one may be urged as an objection ; but the expense of one, on the ordinary construction, is often as much as both would be, if the coppersmith were properly directed. Coppers are generally made of twice or thrice the weight that is necessary. The sides can scarcely be too thin, and the bottom, if it will bear the weight of a man to stand while cleaning it, is of quite sufficient thickness. It should in all cases be well hammered and raised inwards, like the bottom of a wine-bottle ; which not only strengthens it, but allows the worts to drain with more rapidity from the hops. In family coppers, the bottom can be scoured without any great pressure or weight.

Beside the saving in price, a thin-bottomed copper is much more easily heated, and less liable to wear, than a thick one. The inner surface of the bottom can never be hotter than the fluid which it contains : the outer surface is of course as hot as the flame which envelopes it. In a liquor copper, therefore, the inside can never exceed the heat of boiling water ; and, if we could imagine a copper-bottom to be infinitely thin, the heat of the side next the fire would be absorbed, by passing through the copper as fast as it were generated. It is on this principle that water may be made to boil on a folded piece of writing-paper. On the other hand, when the bottom of the boiler is thick, the outer surface is submitted to the heat of the fire some time before it communicates with the liquor within. The metal becomes oxidated, and comes off in scales, or, if the scales remain, they render it more impervious to the heat, so as in some cases to take double the time of a thin bottom, before the liquor can be brought to the requisite heat. The difference of wear is an obvious consequence. We have ourselves made use of a twenty barrel liquor copper, which (the discharge cock included) did not weigh three hundred pounds, and we found it quite sound at the end of fifteen years, without having needed the slightest repair during all that period. The London allowance for a copper of that size would be eight or nine hundred weight.

With respect to the size of brewing-coppers, the liquor and wort coppers should be alike, and the contents of each must be regulated by the sort of beer to be brewed. If small beer alone, with three *mashes*, the first mash would

require from three to four barrels of hot liquor per quarter of malt, according to the quality ; and, as it is always convenient to have more liquor than is needed for the mash, so as to get the second mash liquor ready in time, he who would brew small beer in this way, ought to have a copper which would contain five barrels of liquor for every quarter of malt that he intends to brew at a time. Were he to brew strong ale, with small beer in succession, or porter alone, a copper containing about three barrels for every quarter of the mash would be a sufficient size. We are aware that many public, as well as private brewers, contrive to manage with a single copper, by means of pancovers and other clumsy shifts ; but our business is to teach the most convenient (which will always be found the most profitable) method of conducting the operation.

§ 3.—Of the Furnace.

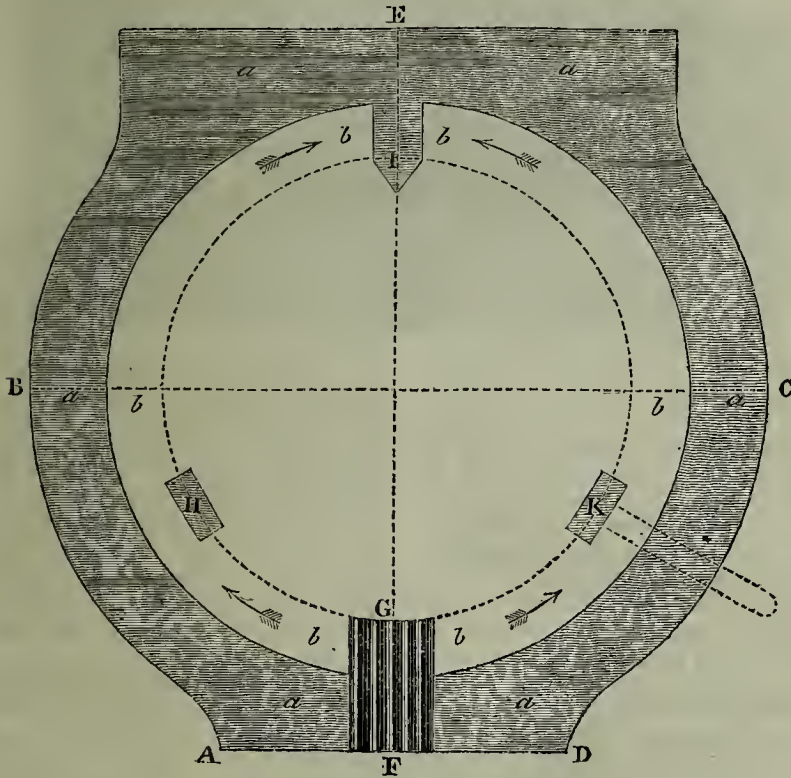
Although the construction of the fireplace and other building (*setting*) of the copper is usually entrusted to the bricklayer, yet a well-going furnace is of such importance to the brewer, that we cannot pass over it in silence. In most manufactories, an ill-built fireplace is merely the cause of additional destruction of fuel, and unnecessary delay ; but, in the brewery, the consequence is often more serious. If, for example, the second mashing liquor cannot be raised to the proper heat within a few minutes of a given time, the whole brewing of the day is in imminent danger of being lost. We shall, therefore, describe our method of *setting* a copper, the utility of which we have experienced for many years. It has the double advantage of being cheap, and, at the same time, equally applicable to coppers of any size.

There are a few general remarks which apply to every plan of *setting*. The furnace-bars, or grating on which the fuel is burnt, should bear a fixed proportion to the lower surface of the copper on which the heat is expended ; but in this respect the artists do not materially differ. The same may be said of the height between the furnace-bars and the bottom of the vessel, which can scarcely be less than twelve, or more than eighteen, inches. The ash-pit should be as wide as the furnace-bars, and may descend as low as we please. Allowing the furnace-bars to be an inch and a half wide, and half an inch asunder, the

air will be admitted, to supply the fire, through an area equal to one-fourth of the area of the fireplace. This air has to pass into the chimney, in an expanded form, accompanied with the smoke and vapour of the fuel, and in that state will occupy about double its former bulk. The chimney ought, therefore, to have a sectional area equal to half that of the fireplace; and, if so, it will only be the want of height in the chimney that can prevent a proper draught. These things being premised,

Let A B E C D (*fig. 1.*) be a flat piece of masonry, or brickwork, level with the furnace bars G F, and raised from the floor to the height of the ash-pit, which is immediately below the bars, and where only the building is not solid. Draw the dotted circle G H I K, exactly equal in size to the bottom of the copper. Opposite to the middle of the furnace G F erect the prop I, and at H and K, two other props, raising all three to the height at which you mean to fix your boiler above that of the furnace-bars.

Fig. 1.



Place the rim of the bottom of the copper upon these props, which, as proper supports, must be built of fire-brick or of fire-stone. If the copper be very large, intermediate props may be built (always in the dotted circle), so as to support it for a time, were one of them to give way.

Let the surrounding part of the building *a, a, a, &c.* be carried upwards, higher than the bottom of the copper, by ten, twelve, fifteen, or any number of inches at pleasure, leaving a vacuity *b, b, b, &c.* around the copper to the height thus fixed upon, when it is to be covered at top by means of bricks leaning from the wall *a, a, a, &c.*, to the

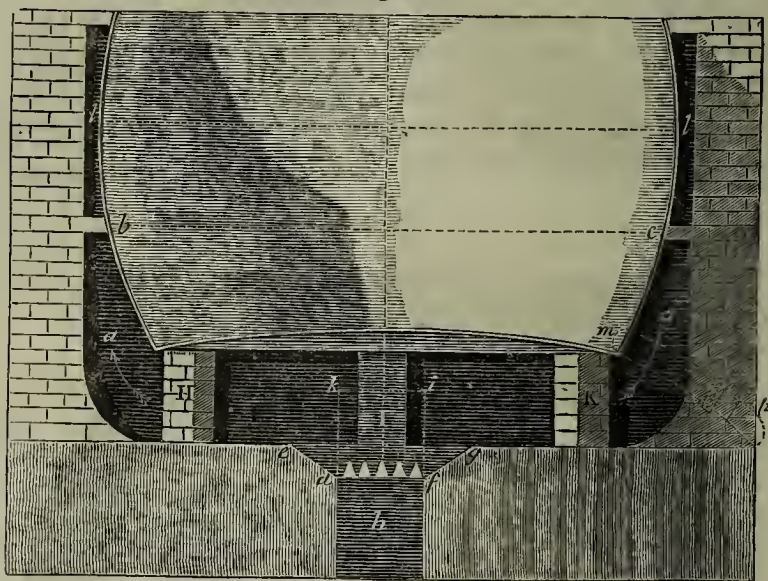
sides of the copper, the aperture not requiring a greater width at that height than the length of a brick: nor, indeed, in any place, need the aperture be more than from nine to twelve inches wide, unless the boiler be very large, in which case it may be covered by an arch. The prop I, should be continued across this vacuity, and raised so as the flame, when it has reached the roof of the aperture, shall just have sufficient room to pass easily over on both sides, into the chimney *c, d, e, f*, as represented at *fig. 3*, in which the prop I is marked on a section by the same letter I. By keeping the entry to the chimney at this

height, the whole exposed part of the copper will be wrapped in flame; for it should always be kept in mind that the flame will rise as high and no higher

than the opening by which it is allowed to enter the chimney.

Fig. 2 is a vertical section on the same scale, with the copper in its place.

Fig. 2.



The lower part of this copper, being in the form of a truncated cone, allows the bottom (literally so called) to be smaller, and consequently lighter, than if the vessel had been cylindrical; while the flame, mounting up the sides at *a, a*, gives the same heating power, as if the bottom had been of a diameter equal to the line *b c*. After the circular vacuity is closed at *b* and *c*, the building round the copper (until again closed at the top) should be kept three or four inches from the sides, as represented at *ll*; and this thin zone of air will prevent the escape of the radiant heat, more effectually than would be done by two feet of solid masonry. The sides of the furnace are sloped to keep the fuel upon the bars, as in the lines *d e* and *f g*. This section is presumed to be made at the inner end of the furnace, where the ash-hole *h* ends. The place of the furnace door (which is cut off in front) is represented by the dotted rectangle *d, f, i, k*. The lighter shade *l*, seen behind this rectangle, is the prop *I* mentioned at (*fig. 1.*) The other two props *H* and *K*, are here also shown by the same letters.

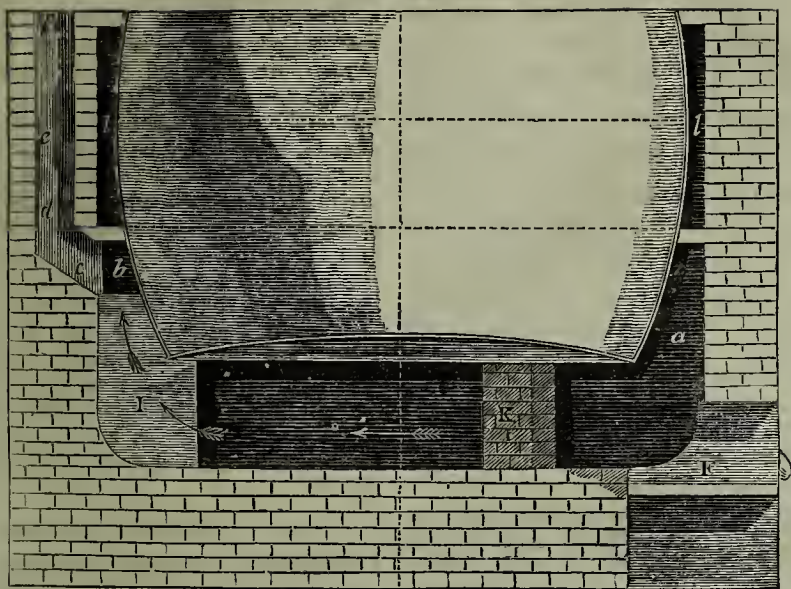
Fig. 3 is another section of the copper and its building, through the line *E F* on the plan *fig. 1.* *F* is a section of the furnace; *I* is a central section of the prop *I* so often mentioned; and *K*

is the prop *K* of *fig. 1.*, the other prop being supposed to be cut away. The dark shade *a* is part of the open space which surrounds the lower part of the copper; and *b* is a portion of the same open space, the rest being covered by the prop *I*, over which prop, and on both sides of it, the flame ascends to *b*, entering the chimney *c d e f* at *c*. The dark narrow spaces *ll*, represent the same zone which was explained in *fig. 2.*

It will be observed, that the discharge pipe, *m n*, has to pass through the flame; it must, consequently, be a simple copper tube, riveted to the boiler, and joined to the cock, *p*, by a flange at *n*. This will, however, in a twenty-barrel copper, save a hundred weight, at least, of lead, which the coppersmiths usually pour into a socket, when joining a cock to a boiler, and which is weighed to the purchaser as copper. To be sure, were it not for this base metal, as well as the excessive weight of the whole, the coppersmith would be obliged to charge more per lb. for his labour. We do not mention these things as frauds, but as absurdities.

It would be out of our way to dwell long upon the erection of furnaces, and, therefore, we have left many of the details unnoticed. For our own part, we

Fig. 3.



have generally found *ash-pit doors* and *upper dampers* more troublesome than useful—especially the latter—which are seldom so tight as to prevent a stream of cold air from entering the chimney, and thus disturbing the draught. We must not, however, neglect to mention what we have found from experience to be a great improvement in furnace-doors. These are often extremely troublesome. By their warping when thin, and shaking the building when weighty, they are perpetual sources of vexation. The improvement we allude to is cheap and simple, and by it we get immediate access to the furnace, without having to shove the coals through a passage two feet deep, which is made solely to keep the door steady on its hinges. The iron frame in front of the furnace is, in this case which we recommend, like that of the ordinary door-way, except that it is quite flat, (without any projection for latch or hinge,) and has a horizontal plate, about three inches broad, on a level with the bars, on which the substitute for a door is to rest. This door is a square, or rectangular fire-brick, (what is termed a *Welsh tile*,) about two inches thick, and of sufficient size to cover the opening of the fire-place, and an inch or two more on each side and at top, as far as the front-plate will allow. This tile is surrounded by a well-fitted hoop of iron, which, by means of a screw on one side, presses the other sides together so as to keep the tile firm. On the middle of the upper side

of the hoop is a staple, by which it is attached to a light iron chain, and the tile is so balanced, that when suspended the sides hang perpendicular. The chain is then passed over a pulley, so as the tile may drop directly before the fire-place, upon the plate above mentioned; when a weight exactly counterbalancing the tile is attached to the other end, so that this door may be raised, or lowered, at pleasure, with a very slight effort. By means of two or more pulleys, the countervailing weight may, like a bell-pull, be sent to any corner of the brew-house.*

CHAPTER III.

Of Brewing Utensils (continued).

§ 1.—*Of the Mash-Tun.*

SIMPLE as it still is, the mash-tun of former times was yet simpler than now. It was a tub with a hole in its centre, which was plugged by means of a round shaft of wood that stood perpendicularly through the goods. When the mash was to be drawn off, this shaft, which was called the *Tap-tree*, was loosened (but not altogether pulled out) from the hole, which, being *conical*, allowed the worts to descend in a small stream into the underback; and the filtration was assisted by a wisp of straw that had previously been wound about the *tap-*

* We are indebted for our knowledge of this useful contrivance to the late Mr. Parkes, who has described it in his "Chemical Essays, Vol. II."

tree, close to that part which acted as a plug to the tun. It is hence that the brewers still use the phrases of *setting-tap* in the sense of beginning to let off the worts from the *goods*; and *tap-spending*, or *tap-spent*, to announce that the goods are draining, or drained. Instead of this rude instrument, a *false bottom*, pierced with holes, is universally used; and the liquor, which was formerly poured upon the top of the malt, is now, in most cases, carried down the inside of the mash-tun, by a trough, and made to enter between the two bottoms, whence, rising upwards through the holes of the false bottom, it forces its way among the *goods*, with which it is then intimately mixed by the *mashing-machine*, or with *mashing-oars*.

The size of the mash-tun must be regulated by the quantity of malt and the quality of the beer for which it is to be employed. From this may be calculated the largest space that will require to be occupied by the goods and liquor of the mash; after which, five or six inches additional depth must be allowed, to leave room for the agitation when mashing. The liquor between the bottoms is not effective, and should, therefore, be as little as possible, consistent with the prevention of the risk of choking, with any deposit that might fall from the goods. An inch between the bottoms will be quite sufficient; in small areas, less. The holes of the false bottom should be burnt rather than bored, lest the pores of the wood should collapse with the hot liquor, which might put the first brewing in danger. To prevent this risk, by making wider holes, would be still worse: the holes should be conical; the lower part from a quarter to three-eighths of an inch diameter; but at the upper surface they ought not to exceed an eighth; the bottom should fit the sides of the mash-tun, and its parts should meet so as not to leave a chink.

We must advertise the private brewer, that, if he brew with a mixture of raw grain, it may sometimes happen that the goods in the first mash will sink to the lower part of the mash-tun and leave the wort floating above, without being able to filtrate through the condensed mass. To prepare for this contingency, the upper part of the trough that passes down the inner circumference of the tun and leads to the space between the bottoms, should be

pierced with holes in the same manner as the false bottom. These holes, when not needed, may be shut by an interior trough, or by boards; and, when there is occasion to let off the worts from the top of the mash, the interior trough, or boards, may be pushed downwards, and the supernatant worts will pass through the holes, down the trunk, and, communicating with the space between the bottoms, may be drawn off in the same manner as if they had filtrated through the goods. With the second mash, this process will seldom, if ever, be necessary. In these observations we have supposed the mash-tun trough to be a close tube, but some give it only three sides, trusting to the inner surface of the tun (to which it is applied) for the fourth.

§ 2.—Of Mashing Machines.

Concerning mashing machines, we have very few observations to make. In large works they save much of human labour; but we should imagine that, until the mash extends to twenty quarters, they produce very little saving, unless under peculiar circumstances; such as the advantage of a waterfall, where the power costs nothing. In small works, and in private families, it is wholly out of the question. Oars are there the cheapest and the best mashing instruments.

§ 3.—Of the Hop-back.

After the wort is sufficiently boiled, along with the hops, it has to be carried into the coolers. If an airy situation can be had for this purpose, below the level of the discharge-cock of the wort-copper, the wort may be run off into the cooling-backs, either by means of a pipe or an open shoot, and the hops separated by means of a drainer in a corner of the first cooler, or *back* as it is termed by the excise; but when they cannot be cooled except at a higher elevation, the worts must be carried thither, either by hand, or by means of a pump. This pump may be placed directly into the copper; but, in that case, if the hops be in a great proportion, they will need to be inclosed in a net to prevent any accident from the choking of the valves. The ordinary way is to empty the copper into a hop-back, either round or square, on the upper part of which is fixed a drainer, (a perforated smaller vessel,) to keep back the hops. The pump is placed in the hop-back,

and from thence raises the wort to the coolers. This wort-pump must differ from the common suction pump, if we expect *immediate* action. The lower valve must be placed at, or near, the bottom of the back; for that of the piston rod must be immersed in the fluid, as long as it gives out steam, before the action of the pump will be free. The valves, too, should be of metal, to resist the heat.

§ 4.—Of the Coolers.

It is of importance that the worts when drawn from the copper should be cooled, as speedily as possible, to that degree which fits them for the fermenting tun. This is more especially necessary in summer, and, therefore, the cooling back should be placed in that quarter where there is the best succession of fresh air; and the worts, if it can at all be prevented, ought never to lie above two inches deep in the coolers. This should regulate their size. The word *Coolers* is used in the plural, because two of these are indispensable when we make two kinds of beer from the same brewing; and even in single *Gyles*, if we make a *Return*. The two latter terms will be afterwards explained. One cooler ought to be placed so as to run into the other; and this, when we have occasion to speak of it, we shall call the *first* cooler,—the other the *second*. Sometimes three, or even four coolers are used, but these are more for conveniency than necessity.

Various contrivances have been proposed, and some of them adopted, for expediting the cooling of worts. That which is most commonly practised is the *fanning machine*, which is placed immediately above the cooler; and by the rapid revolution of its horizontal boards, or arms, produces a whirlpool of air which assists the ascent and dispersion of the steam. Whether or not this has any effect against the preservative quality of the beer, we are unable to determine. Reasoning *a priori* we should judge it to be unfavourable; but we have no support from experience. The *fanners* are employed only in the summer season, when beer for keeping is never brewed.

Another mode of cooling is to pass the worts through cold water, by means of a worm, in the manner of the distillers; but in that case the water would need to be plentifully supplied. Besides, it must be taken immediately from the spring, for that which is exposed

for only a short time to the atmosphere, acquires its temperature, and gives no advantage over that of spreading the wort, in thin sheets, to the open air. Further—and we wish our observation to be applied to every attempt at improvement in his art—the public brewer ought to be very wary of introducing into his work any manipulation that is new. We knew a brewer whose situation was peculiarly adapted for the cooling method of which we speak. He practised it successfully for years, under the daily surveillance of the excise. Another superior officer at length came into the round. He found a clause, in an Act of Parliament, which made the process, in his view, *illegal*, although not *fraudulent*. The brewer was prosecuted in the Court of Exchequer. Instead of compromising the fault, he *foolishly* let it go to trial. He was *acquitted*, after his ingenuity had received an *eulogium* from the judges;—but *the Crown never pays expenses!*

The article *Brewing*, in the “Supplement to the Encyclopædia Britannica,” (which was written by Dr. Thomson), contains the following remarks on the subject of which we now treat:—“When the brewer is obliged to make ale in warm summer weather, it is material to reduce the temperature as low as possible. In such cases, great advantage would attend cooling the worts in coolers without any roof, or covering whatever, but quite open to the sky; because, in clear nights, the wort might be cooled, in this way, eight or ten degrees lower than the temperature of the atmosphere. The reason is obvious. It is owing to the rays of heat which, in such a case, radiate from the wort, and are not returned again from the clear sky. Wort being a good radiator of heat, would be particularly benefited by this method of cooling.” “A roof, perhaps, might be contrived, composed of very light materials, which might be easily slid off, or which might turn upon a pivot.” “We have little doubt that wort might easily be cooled down to the freezing point, if requisite, in our warmest summer weather.”

§ 5.—Of the Fermenting Tuns.

When the wort is considered as sufficiently cool, it is carried to the *Fermenting Tuns*, or the *Fermenting Squares*; some brewers using circular and others rectangular vessels for that purpose. The circular are, in our opinion, decidedly the best. Having no corners;

they are more easily kept clean; and, in low fermentations, in the winter months, they are less liable to be chilled. The fermenting tuns are commonly termed *Gyle-tuns*, or *Working tuns*.

The size of the gyle-tun is regulated by the quantity of worts that have to be fermented within it at a time. It must, however, hold more than that quantity, to keep room for the head of yeast which rises during the progress. This head, if the vessel be cylindrical, is in proportion to the depth of the worts, without regard to the diameter of the tun. In certain modes of fermentation it may rise to a third, or even half of that depth. The number of tuns will depend on the more or less rapid succession of the brewings, and the time that they are suffered to remain before cleansing.

There are differing opinions with respect to using open or shut tuns, in the process of fermentation. Patents have been granted for particular applications of the latter mode, both in France and in this country, but of this we shall treat more appropriately when we have to investigate the nature and result of the operation in the *gyle-tun*.

§ 6.—Of cleansing Casks, Stillions, and Store Vats.

When the beer has received its assigned portion of fermentation in the tun, it is *cleansed*, that is, drawn off into other vessels. These are usually barrels, or other casks of a similar shape, in which the fermentation is finished by causing the yeast to be discharged from the bung-holes into *tubs*, or *stillions*, over which the barrels are placed. In order to keep up this purgation until all the yeast is wrought off, the *casks* are filled up, from time to time, with other beer. Some brewers take another mode, and finish the purgation in the tuns, by skimming off the yeast as it rises, after the fermentation has become languid. The comparative advantage of these modes will come again under our consideration. In porter-breweries, the beer, when it has ceased working, is usually turned into large close tuns termed *Store-vats*, in which it is mixed up with different brewings to suit the taste of the customers. Ale brewers, on the contrary, seldom rack their ale, but send it out in the casks where it received its final purgation. These practices, however, are in neither case universal. The reasons that determine these and other methods of cellaring,

in the minds of the several brewers, will afterwards appear.

§ 7.—Of the Arrangement of the Plant.

The general disposition of the *fixed utensils* (or *plant*) of a brewery must vary so much with the situation and extent of the building, that we can only give a general outline of the objects to be kept in view: leaving it to be filled up by the judgment of the engineer, or the ability of the proprietor.

If water cannot be had from a source sufficiently high, it should be raised to a *liquor-back* in quantity equal at least to one day's consumption, and high enough to command the whole work. Pipes, from this liquor-back, should be carried to every part of the brewery where they may be requisite. The liquor-copper should be the next in elevation, and from it, too, pipes should be carried. Immediately under, and as near as possible to the liquor-copper, we would place the *mash-tun* with a roomy stage, and, on the same floor, or a little higher, the *grinding machine*—at least that part of it where the ground malt called *grist* is given out. The mash tun should empty itself directly, by means of a pipe and cock, into the *wort-copper*; this again into the *hop-back*; and the hop-back, by means of a pipe or shoot, into the *first cooler*. The first cooler should run, if required, into the second, and both should communicate with a horizontal pipe running in front, and as low as the bottom of the gyle-tuns, (for these should be all on a level,) and communicating with each gyle-tun by stopcocks. From this horizontal pipe another should be carried to a contiguous cellar, below ground, which, by the assistance of screw-cocks and leather pipes, might cleanse any of the tuns into the casks. How much of all this can, in any particular case, be accomplished, we have here no means of determining. The plan of filling the gyle-tuns at the bottom instead of the top is not usual, but the young brewer will find it very commodious.

We are aware that many of the remarks and recommendations which we have hitherto given, will be considered as impracticable by private gentlemen, for whose use, as well as that of the public brewer, these pages are intended; but the accurate consideration of every subject has its use, and without this previous analysis we could scarcely hope to render the other parts of our work intelligible. The private brewer may

have a more scanty store of utensils than those we have enumerated. They may even change their identity: his liquor-copper may become his wort-copper; his mash-tun may be metamorphosed into a gyle-tun; but he will understand what we mean, when we mention the different names, and will recognize the actors in their changes of character and dress.

CHAPTER IV.

Of Instruments.

§ 1.—*The Thermometer.*

BREWING is a philosophical art; and has gained advantages from some of those instruments which philosophy has invented. Few, if any, of the arts depend so much on the regulation of heat; and, notwithstanding, the introduction of the thermometer into the brewery was, we believe, not earlier than the middle of the last century. We are sure that then it was far from general; and even now it is unknown to nine-tenths of the private brewers. We are not, however, to judge from this circumstance, that our ancestors could not make good beer. They did so, but by no fixed rule. The guess-work often succeeded; and when, as was frequently the case, a brewing was *blinked* or otherwise spoiled, the blame was laid upon thunder, or upon witchcraft. Yet, even in those times, there were scientific brewers, who were able to do to-day what they did yesterday, though they could not communicate their knowledge. As is said of the blind,—the *other* senses became more acute from the want of artificial instruments; and the taste, touch, hearing, smell, and sight, were more forcibly put in requisition. We know a public brewer, still in business, in a country town, whose scientific acquirements are of the lowest rank, who exposes only the bottom of his copper to the fire, keeping the sides uncovered and polished; and who, nevertheless, fixes the heats of his mashing liquor, with surprising exactness, by the sound which his copper gives when beat with his **KNUCKLES**. With all this, he has little or no musical ear.

The thermometer is applicable and useful in every stage of the brewing process. It ascertains the heat of the mashing liquor, and of the worts when draining from the mash-tun. In the coolers, it shows when the worts are ready to let down for fermentation;

and in the gyle-tun it marks the progress, as far as it is notified by the increase or diminution of the heat. For the latter purpose there are tun-thermometers, from three to three and a-half feet long, which can be immersed in the worts, while all that is necessary of the scale overtops the froth of the head. An improved thermometer for the liquor-copper is still a *desideratum*. In high heats the steam covers the tube and obscures the mercury, so as easily to produce a mistake. We have often proposed, that a red glass bead should be introduced into the tube, which would swim on the top of the metallic fluid; but we have never been able to find an artist who would undertake to produce such an instrument, though it would certainly procure a ready sale. Perhaps a slight portion of coloured glass-dust might be inserted, so as to answer the purpose.

§ 2.—*The Saccharometer.*

The principle and construction of the *hydrometer* (or *areometer*) have been already explained in our “*Treatise on Hydrostatics*.” The *saccharometer* is nothing else but a *hydrometer*, whose scale is calculated so as to render it peculiarly fitted for measuring the specific gravities of worts, as compared with water. The infusion of malt is *sweet*, and without stopping to investigate whether or not that sweet substance (which is extracted from the malt and increases the weight of the water) is homogeneous with the sugar (Latin *saccharum*) of the cane, the infusion is termed *saccharine*; the additional gravity which it exhibits beyond that of water is said to be caused by the *saccharine matter*, and is measured by the *saccharometer*.

The first instrument under the name of a *saccharometer* was constructed, and sold to the trade in 1784, by Mr. John Richardson, then a brewer at Hull. Other saccharometers have since appeared with various claims to superiority; but the fundamental principle of all is the same, and though Mr. Richardson’s instrument has been *theoretically*, it has never been *practically*, improved. Extreme nicety is not necessary to the Brewer. What is wanted is a *cheap instrument*, which might be bought by private families; for we know of none at present that can be had under three guineas, except certain rudely-constructed glass ones, which

have no pretensions to accuracy. We trust that we shall soon be able to supply this deficiency.

Mr. Richardson's saccharometer, if adapted to the imperial gallon, may be thus described :

The part *A* (fig. 4) is a hollow ball of copper, having a flat brass stem *c d*, and a weight *a* of the same metal affixed by the foot-stalk *g h*. The weight *a* is regulated so as the instrument shall sink in distilled water of 62° to the point *b* of the scale *e b*, which is divided into ten equal parts. A barrel (36 gallons) of pure water at 62° heat, weighs 360 pounds avoirdupois ; and the instrument is so regulated that, if put into a liquid weighing 361 pounds per barrel, it would rise to the mark *e*. Each of the divisions between *e* and *b* will then represent tenths of a pound. There are weights (having holes in their centres) marked 1, 2, 3, 4, 5, 10, 20 and 30. These, respectively, represent pounds weight, and are put, as required, on the top of the stem, resting on the projection *d*. So, for example, if when putting on the weight marked 10, the instrument sinks in a wort to the point *b*, a barrel of that wort, at the heat above specified, would weigh exactly ten pounds more than a barrel of pure water. If the instrument shall cut the surface at two of the divisions below the point *b*, in that case a barrel of the liquid would weigh 10.2 lb. more than a barrel of water—that is, 370.2 pounds. The length of the instrument is about eight inches, to which the ball is proportioned, as in the figure. The worts are understood to be cooled down to a certain heat (in our description 62°), and an allowance is made at other heats, as directed by a table which accompanies the instrument.

The water used by the Brewer is seldom or never pure, but is often a tenth, and sometimes a half of a pound weightier per barrel. This should be kept in mind in taking the gravities of the worts, or the instrument may be regulated to the water by shortening *a h* ; the part *g* sliding into the socket *g h*.

The common hydrometers, instead of proportioning the specific gravities of fluids to 360 parts of water, as is here done, compare them with 1000 parts ; as may be seen in the Table of Specific

Gravities, given in the Treatise on Hydrostatics. The principle, nevertheless, is the same. Sea-water, for example, in that table, is marked 1028, while distilled water is 1000 : that is, the same measure of the latter which would weigh 1000 ounces, or pounds, would, if filled with sea-water, weigh 1028. If we wish to reduce the saccharometer indications to the proportion of a thousand, we have only to multiply them by $2\frac{2}{3}$, because 1000 is $2\frac{2}{3}$ times 360. Thus a wort which shows 9 lb. by the saccharometer is equal to 25 parts of 1000, and in the table of gravities would be written 1025. But the Brewer never adds the weight of the water when speaking of his worts. A wort, the barrel of which weighs 370 pounds, is merely called a ten pound wort, and in this way all his calculations are made.

For the convenience of those who wish to compare specific gravities generally, as they appear in philosophical works, we subjoin the following table. The figures of the left hand marginal column are understood to be pounds ; and those of the upper horizontal line, tenths of a pound weight, per barrel, as indicated by the common saccharometer. The body of the table contains specific gravities, extending to tenths and corresponding with the different weights, water being reckoned 1000. An example or two will be sufficient to show the mode of consultation.

Suppose we have a wort of 14 lb., and wish to know its specific gravity. In the left-hand margin we find 14 ; and next to that in the adjoining column marked at top by a cypher, there being no tenths, we find 1038.9, the specific gravity required. Again, let the saccharometer-weight be 32.4 lb. Opposite to 32, in the margin, and in the same horizontal line, in the column headed .4, we have 1090, for the equivalent specific gravity ; and thus that of any wort under 50 pounds weight may readily be found.

The reverse of this comparison is equally easy. Thus, suppose we have a wort which shows a specific gravity of 1109.5 by the common hydrometer ; and we want to know how many pounds heavier a barrel of such worts is than a barrel of water : we seek, in the body of the table, for the nearest number to 1109.5, which we find to be 1109.4. This sum is in the column headed .4, in the horizontal line with the left-hand margin 39 ; and therefore 39.4 is the weight sought for.

Fig. 4.



TABLE FOR REDUCING POUNDS AND TENTHS OF ADDITIONAL GRAVITY
PER BARREL INTO PARTS OF 1000.

lb	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	1000.0	1000.3	1000.6	1000.8	1001.1	1001.4	1001.7	1001.9	1002.2	1002.5
1	1002.8	1003.1	1003.3	1003.6	1003.9	1004.2	1004.4	1004.7	1005.0	1005.3
2	1005.6	1005.8	1006.1	1006.4	1006.7	1006.9	1007.2	1007.5	1007.8	1008.1
3	1008.3	1008.6	1008.9	1009.2	1009.4	1009.7	1010.0	1010.3	1010.6	1010.8
4	1011.1	1011.4	1011.7	1011.9	1012.2	1012.5	1012.8	1013.1	1013.3	1013.6
5	1013.9	1014.2	1014.4	1014.7	1015.0	1015.3	1015.6	1015.8	1016.1	1016.4
6	1016.7	1016.9	1017.2	1017.5	1017.8	1018.1	1018.3	1018.6	1018.9	1019.2
7	1019.4	1019.7	1020.0	1020.3	1020.6	1020.8	1021.1	1021.4	1021.7	1021.9
8	1022.2	1022.5	1022.8	1023.1	1023.3	1023.6	1023.9	1024.2	1024.4	1024.7
9	1025.0	1025.3	1025.6	1025.8	1026.1	1026.4	1026.7	1026.9	1027.2	1027.5
10	1027.8	1028.1	1028.3	1028.6	1028.9	1029.2	1029.4	1029.7	1030.0	1030.3
11	1030.6	1030.8	1031.1	1031.4	1031.7	1031.9	1032.2	1032.5	1032.8	1033.1
12	1033.3	1033.6	1033.9	1034.2	1034.4	1034.7	1035.0	1035.3	1035.6	1035.8
13	1036.1	1036.4	1036.7	1036.9	1037.2	1037.5	1037.8	1038.1	1038.3	1038.6
14	1038.9	1039.2	1039.4	1039.7	1040.0	1040.3	1040.6	1040.8	1041.1	1041.4
15	1041.7	1041.9	1042.2	1042.5	1042.8	1043.1	1043.3	1043.6	1043.9	1044.2
16	1044.4	1044.7	1045.0	1045.3	1045.6	1045.8	1046.1	1046.4	1046.7	1046.9
17	1047.2	1047.5	1047.8	1048.1	1048.3	1048.6	1048.9	1049.2	1049.4	1049.7
18	1050.0	1050.3	1050.6	1050.8	1051.1	1051.4	1051.7	1051.9	1052.2	1052.5
19	1052.8	1053.1	1053.3	1053.6	1053.9	1054.2	1054.4	1054.7	1055.0	1055.3
20	1055.6	1055.8	1056.1	1056.4	1056.7	1056.9	1057.2	1057.5	1057.8	1058.1
21	1058.3	1058.6	1058.9	1059.2	1059.4	1059.7	1060.0	1060.3	1060.6	1060.8
22	1061.1	1061.4	1061.7	1061.9	1062.2	1062.5	1062.8	1063.1	1063.3	1063.6
23	1063.9	1064.2	1064.4	1064.7	1065.0	1065.3	1065.6	1065.8	1066.1	1066.4
24	1066.7	1066.9	1067.2	1067.5	1067.8	1068.1	1068.3	1068.6	1068.9	1069.2
25	1069.4	1069.7	1070.0	1070.3	1070.6	1070.8	1071.1	1071.4	1071.7	1071.9
26	1072.2	1072.5	1072.8	1073.1	1073.3	1073.6	1073.9	1074.2	1074.4	1074.7
27	1075.0	1075.3	1075.6	1075.8	1076.1	1076.4	1076.7	1076.9	1077.2	1077.5
28	1077.8	1078.1	1078.3	1078.6	1078.9	1079.2	1079.4	1079.7	1080.0	1080.3
29	1080.6	1080.8	1081.1	1081.4	1081.7	1081.9	1082.2	1082.5	1082.8	1083.1
30	1083.3	1083.6	1083.9	1084.2	1084.4	1084.7	1085.0	1085.3	1085.6	1085.8
31	1086.1	1086.4	1086.7	1086.9	1087.2	1087.5	1087.8	1088.1	1088.3	1088.6
32	1088.9	1089.2	1089.4	1089.7	1090.0	1090.3	1090.6	1090.8	1091.1	1091.4
33	1091.7	1091.9	1092.2	1092.5	1092.8	1093.1	1093.3	1093.6	1093.9	1094.2
34	1094.4	1094.7	1095.0	1095.3	1095.6	1095.8	1096.1	1096.4	1096.7	1096.9
35	1097.2	1097.5	1097.8	1098.1	1098.3	1098.6	1098.9	1099.2	1099.4	1099.7
36	1100.0	1100.3	1100.6	1100.8	1101.1	1101.4	1101.7	1101.9	1102.2	1102.5
37	1102.8	1103.1	1103.3	1103.6	1103.9	1104.2	1104.4	1104.7	1105.0	1105.3
38	1105.6	1105.8	1106.1	1106.4	1106.7	1106.9	1107.2	1107.5	1107.8	1108.1
39	1108.3	1108.6	1108.9	1109.2	1109.4	1109.7	1110.0	1110.3	1110.6	1110.8
40	1111.1	1111.4	1111.7	1111.9	1112.2	1112.5	1112.8	1113.1	1113.3	1113.6
41	1113.9	1114.2	1114.4	1114.7	1115.0	1115.3	1115.6	1115.8	1116.1	1116.4
42	1116.7	1116.9	1117.2	1117.5	1117.8	1118.1	1118.3	1118.6	1118.9	1119.2
43	1119.4	1119.7	1120.0	1120.3	1120.6	1120.8	1121.1	1121.4	1121.7	1121.9
44	1122.2	1122.5	1122.8	1123.1	1123.3	1123.6	1123.9	1124.2	1124.4	1124.7
45	1125.0	1125.3	1125.6	1125.8	1126.1	1126.4	1126.7	1126.9	1127.2	1127.5
46	1127.8	1128.1	1128.3	1128.6	1128.9	1129.2	1129.4	1129.7	1130.0	1130.3
47	1130.6	1130.8	1131.1	1131.4	1131.7	1131.9	1132.2	1132.5	1132.8	1133.1
48	1133.3	1133.6	1133.9	1134.2	1134.4	1134.7	1135.0	1135.3	1135.6	1135.8
49	1136.1	1136.4	1136.7	1136.9	1137.2	1137.5	1137.8	1138.1	1138.3	1138.6

§ 3.—*Assay Jars.*

These are used for the purpose of holding the worts which are to be weighed by the saccharometer. Their number is not limited, and may be only one or half a dozen, if it be wished to keep samples of the several worts. They are cylindric vessels of common tinned iron, about eight inches long and two and a-half diameter, which size gives sufficient space to swim the saccharometer. They have each a small handle and a lid, as represented in *fig. 5*.

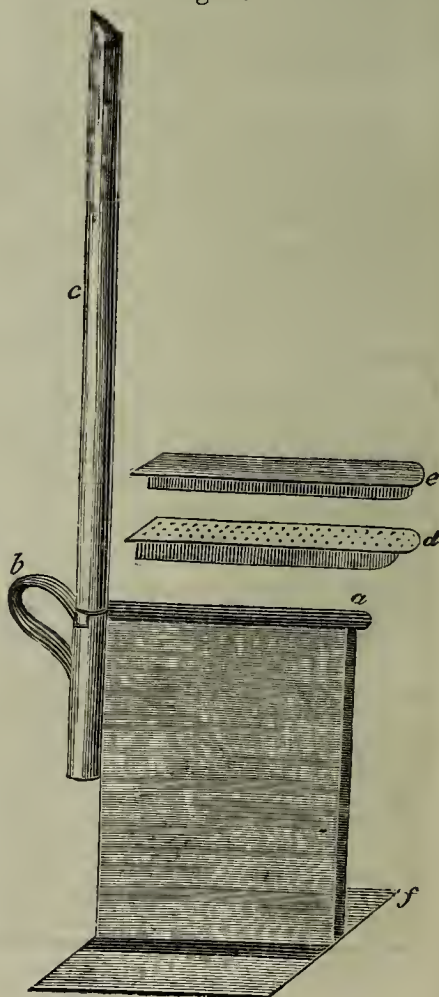
Fig. 5.§ 4.—*Refrigerator.*

This is a very necessary article; for though the saccharometers are usually accompanied with tables of expansion to show the allowance for the heat above or below sixty degrees, yet the worts can never be properly weighed, on account of the steam, until they are brought down to 90 at most. This refrigerator is so well described by Mr. Richardson, that we cannot do better than give it in his own words:—

“This instrument may be made of tin, and being intended to contain no more than the quantity of an assay-jar full, its dimensions may be nine or ten inches deep, and its breadth seven inches one way, and half an inch the other, forming a broad and flat, or thin vessel, resembling a tin case, sometimes made use of for the preservation of deeds or other writings. (See *fig. 6*.) The rea-

son of its being made thus thin is, that when charged with hot wort, and plunged into cold water, the effect of the cold may be almost instantaneous, which is nearly the case; for the quantity of wort being less than a pint, and the surface brought into contact with the cold water (the intervention of the tin only excepted), containing about 140 square inches, it may easily be conceived how rapidly the heat must be dissipated.

“The upper part should have a lip *a* for the more conveniently pouring out the wort; and on the opposite side should be a socket, to which a handle, *b*, should be soldered. The use of the socket is to receive a stick, of any convenient length, *c*, which is to fix in the socket by a pin, in the same manner as a bayonet is fixed; by which means it may be fastened in, when the refrigerator is to be dipped

Fig. 6.

into the copper, and taken out, as an incumbrance, when it is charged with wort. It is to have two lids, or covers, *d* and *e*, the rims of which are to slip within the edge of the vessel, as is recommended for those of the assay-jars. One of the covers is to be perforated full of small holes, in order to admit the wort, and at the same time to prevent the hops from entering; the other is to be whole, and is intended to supply the place of the first the moment it is taken out of the copper.

"The length of the stick inserted in the socket is entirely to be determined by circumstances, it being intended only as the means of holding the refrigerator in the wort, till it is filled without endangering the hand from the steam.

"It should have a broad flat bottom, *f*, in order to enable it to stand upright, otherwise there would be a necessity of supporting it in that position."*

CHAPTER V.

Of Solutions and Mixtures.

§ 1.—*Of Solutions.*

WHEN a solid substance is dissolved in a liquid, the specific gravity of the compound is not increased by the whole weight of the solid dissolved. Part goes to the increase of bulk, and this increase differs with the nature of the bodies so united, in such a manner as not to be included under any general law that has been hitherto discovered. There is a marked distinction between mechanical and chemical union. A substance, for example, which has the same specific gravity as water would be suspended in that fluid, and, if reduced to dust, might be thoroughly mixed; but the mixture would be turbid, and the specific gravity of the water would remain the same. The suspended particles would increase the bulk exactly in proportion to the added weight. In chemical unions, however, (although we are pretty ignorant of their cause,) it is otherwise. In the mixture of fluids we are uncertain, previous to experiment, whether their volume will be increased or diminished. In certain proportions of alcohol and water, the diminution of bulk is about three per cent., and, as might be expected from theory, heat is produced. The solution, notwithstanding, remains transparent, without deposition. The

alcohol and the water are united, but neither is decomposed.

The manner in which the hot liquor absorbs the substance, termed saccharine, from the malt, has not been sufficiently observed. It would appear, from a few circumstances which have been noted, that there exists a condensation during the absorption, and that caloric is evolved; for the heat of the mash is often considerably above the mean of the ingredients. This, however, may be occasioned by the action of *Saccharification*, of which we shall afterwards have occasion to speak.

However all these things may be, it is certain that the weight of the dry substance extracted from the malt is much greater than that which is communicated to the specific gravity of the worts; for, if we were to take a barrel of worts which weighed 380 pounds, that is, twenty pounds more than water (as might be shown either by the saccharometer or by actual weighing); and were we to evaporate the water at a low heat until nothing remained but a dry residuum, that residuum would probably be found to weigh about fifty-two pounds: at least, this is nearly the result of experiments that have been made. The specific gravity of this residuum is stated by Dr. Thomson to be 1.532; but, we believe, he was never able to procure it in a solid form. At any rate, as we shall have afterwards to speak of the nature of malt extracts, we shall take our illustration of the present subject from the solution of sugar.

Pure sugar, dry and without vacuities, has a specific gravity of about 1.6, compared with water as unity; that is, a gallon measure of this sugar would weigh sixteen pounds, while water weighs only ten. If, then, we put one gallon measure of this solid sugar into thirty-five gallons of water, we shall (setting aside concentration, if there be any) have thirty-six gallons, or a barrel, of a solution, which will weigh sixteen pounds more than the water with which the sugar was mixed. If, instead of the gallon of sugar, we had put in another gallon of water to fill the barrel, we should then have added only ten pounds to the weight of the thirty-five gallons; so that we have a barrel, of sugar wort, which weighs six pounds more than a barrel of water will do; and these six pounds are all that are shown by the saccharometer. In the one case we have

* "Richardson's Philosophical Principles of the Science of Brewing." 1793.

BREWING.

	35 gallons of water, at 10 lbs. per gallon	350 lb.
And	1 gallon of solid sugar, at 16 lb. per gallon	16
	Or 36 gallons of a solution weighing	366
In the other	36 gallons of water, weighing	360

The difference of weight being 6 lbs.

A barrel, therefore, of a fluid mixture of sugar and water, which weighs six pounds more than a barrel of water, contains sixteen pounds of pure sugar; and this proportion of six to sixteen is found to prevail, with little variation, whatever be the quantity of sugar dissolved, as long as the fluidity is preserved. Thus a wort of 14 pounds would contain nearly $37\frac{1}{3}$ pounds of sugar; because 14 is to $37\frac{1}{3}$ in the ratio of 6 to 16.

When Mr. Richardson constructed his saccharometer, he was not aware of the distinction between the specific gravity of a wort and the quantity of *saccharum* which it contained. He mistook the one for the other, and uniformly spoke of a barrel of wort of ten, twenty, or any other number of pounds, as containing the same number of pounds' weight of fermentable matter. Further, however, than this misnomer, his instrument was accurately as well as ingeniously contrived; and we still consider it to be as well adapted to the brewery as any one that has succeeded it. Pounds and tenths of a pound per barrel are

near enough for the purpose of the brewer, without having recourse to sliding rules, in the use of which he may be apt to err. Besides, this proportional specific gravity is accurately true and obvious to his understanding; whereas the *real* amount of fermentable matter, the discovery of which depends upon experiments that he cannot verify, is in every case an approximation or guess-work, rather than a certainty. The following Table will, at all events, enable him, if he wishes it, to turn his weights into *real fermentable matter*, according to the average of the scales of the more recent saccharometers. The method of consultation is the same as in the Table of specific gravities at page 13. The left-hand marginal column gives the pounds, and the upper horizontal line the tenths of a pound of gravity per barrel; and the body of the Table, in the squares to which the side and top figures respectively point, contain the corresponding qualities of dry saccharine matter, which those gravities are supposed to indicate, expressed also in pounds and decimals of a pound.

TABLE OF POUNDS OF FERMENTABLE MATTER CORRESPONDING TO THE POUNDS PER BARREL OF GRAVITY; AVERAGED FROM THE MODERN SACCHAROMETERS.

	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0		.25	.50	.76	1.01	1.26	1.51	1.76	2.02	2.27
1	2.52	2.77	3.02	3.28	3.53	3.78	4.03	4.28	4.54	4.79
2	5.04	5.29	5.54	5.80	6.05	6.30	6.55	6.80	7.06	7.31
3	7.56	7.81	8.06	8.32	8.57	8.84	9.09	9.32	9.58	9.83
4	10.08	10.33	10.58	10.84	11.09	11.34	11.59	11.84	12.10	12.35
5	12.60	12.85	13.10	13.36	13.61	13.86	14.11	14.36	14.62	14.87
6	15.12	15.37	15.62	15.88	16.13	16.38	16.63	16.88	17.14	17.39
7	17.64	17.89	18.14	18.40	18.65	18.90	19.15	19.40	19.66	19.91
8	20.16	20.41	20.66	20.92	21.17	21.42	21.67	21.92	22.18	22.43
9	22.68	22.93	23.18	23.44	23.69	23.94	24.19	24.44	24.70	24.95
10	25.20	25.45	25.70	25.96	26.21	26.46	26.71	26.96	27.22	27.47
11	27.72	27.97	28.22	28.48	28.73	28.98	29.23	29.48	29.74	29.99
12	30.24	30.49	30.74	31.00	31.25	31.50	31.75	32.00	32.26	32.51
13	32.76	33.01	33.26	33.52	33.77	34.02	34.27	34.52	34.78	35.03
14	35.28	35.53	35.78	36.04	36.29	36.54	36.79	37.04	37.30	37.55
15	37.80	38.05	38.30	38.56	38.81	39.06	39.31	39.56	39.82	40.07
16	40.32	40.57	40.82	41.08	41.33	41.58	41.83	42.08	42.34	42.59
17	42.84	43.09	43.34	43.60	43.85	44.10	44.35	44.60	44.86	45.11
18	45.36	45.61	45.86	46.12	46.37	46.62	46.87	47.12	47.38	47.63
19	47.88	48.13	48.38	48.64	48.89	49.14	49.39	49.64	49.90	50.15
20	50.40	50.65	50.90	51.16	51.41	51.66	51.91	52.16	52.42	52.67
21	52.92	53.17	53.42	53.68	53.93	54.18	54.43	54.68	54.94	55.19
22	55.44	55.69	55.94	56.20	56.45	56.70	56.95	57.20	57.46	57.71
23	57.96	58.21	58.46	58.72	58.97	59.22	59.47	59.72	59.98	60.23
24	60.48	60.73	60.98	61.24	61.49	61.74	61.99	62.24	62.50	62.75
25	63.00	63.25	63.50	63.76	64.01	64.26	64.51	64.76	65.02	65.27
26	65.52	65.77	66.02	66.28	66.53	66.78	67.03	67.28	67.54	67.79
27	68.04	68.29	68.54	68.80	69.05	69.30	69.55	69.80	70.06	70.31
28	70.56	70.81	71.06	71.32	71.57	71.82	72.07	72.32	72.58	72.83
29	73.08	73.33	73.58	73.84	74.09	74.34	74.59	74.84	75.10	75.35
30	75.60	75.85	76.10	76.36	76.61	76.86	77.11	77.36	77.62	77.87
31	78.12	78.37	78.62	78.88	79.13	79.38	79.63	79.88	80.14	80.39
32	80.64	80.89	81.14	81.40	81.65	81.90	82.15	82.40	82.66	82.91
33	83.16	83.41	83.66	83.92	84.17	84.42	84.67	84.92	85.18	85.43
34	85.68	85.93	86.18	86.44	86.69	86.94	87.19	87.44	87.70	87.95
35	88.20	88.45	88.70	88.96	89.21	89.46	89.71	89.96	90.22	90.47
36	90.72	90.97	91.22	91.48	91.73	91.98	92.23	92.48	92.74	92.99
37	93.24	93.49	93.74	94.00	94.25	94.50	94.75	95.00	95.26	95.51
38	95.76	96.01	96.26	96.52	96.77	97.02	97.27	97.52	97.78	98.03
39	98.28	98.53	98.78	99.04	99.29	99.54	99.79	100.04	100.30	100.55
40	100.80	101.05	101.30	101.56	101.81	102.06	102.31	102.56	102.82	103.07
41	103.32	103.57	103.82	104.08	104.33	104.58	104.83	105.08	105.34	105.59
42	105.84	106.09	106.34	106.60	106.85	107.10	107.35	107.60	107.86	108.11
43	108.36	108.61	108.86	109.12	109.37	109.62	109.87	110.12	110.38	110.63
44	110.88	111.13	111.38	111.64	111.89	112.14	112.39	112.64	112.90	113.15
45	113.40	113.65	113.90	114.16	114.41	114.66	114.91	115.16	115.42	115.67
46	115.92	116.17	116.42	116.68	116.93	117.18	117.43	117.68	117.94	118.19
47	118.44	118.69	118.94	119.20	119.45	119.70	119.95	120.20	120.46	120.71
48	120.96	121.21	121.46	119.72	121.97	122.22	122.47	122.72	122.98	123.23
49	123.48	123.73	123.98	122.24	124.49	124.74	124.99	125.24	125.50	125.75

§ 2.—*Mixture of Worts.*

The different extracts from malt, if properly taken, seem to be homogeneous. Whatever be their gravity they unite readily with each other, as well as with water, in all proportions; and the mixture is invariably a mean between two extracts with regard to specific gravity, and equal to both in quantity. This regularity in their union renders it an easy task for the brewer to increase, or diminish the gravity of his worts at pleasure; and, as far as strength is concerned, to fix the value of his beer. We shall here give a few examples of the manner of making up strengths; in order to save repetitions when we make our statements of different brewings:—When there is only one kind of beer made from the same goods (what is termed *Entire Gyles*) the mixture of worts requires no calculation. The strength is fixed by the union of the whole; and if that strength be too small there is no remedy but to boil longer, or to be more careful when we mash for another brewing. If the strength of the whole be too great, they may be brought down by letting water into the wort-copper; but this practice is clumsy, and wasteful: for something better might have been got from the goods by sprinkling, if done before the chance of acidity. It is when two qualities of beer (such as strong and small) are made from the same brewing, that the mixing of the worts requires particular calculation. It is to be premised, in the outset, that the brewer must have tables of the contents of his coppers and working tuns for every inch of their depth, and of the coolers for every tenth of an inch. In public breweries these tables are all drawn up by the excise, in barrels, firkins, and gallons; but it will be found more convenient by the brewer, if they are calculated in barrels and tenths, which is minute enough for the purpose which we have now in view to explain.

Suppose	Barrels.	lb. gravity.	
1st Wort	12	at 35	= 420
2d Wort	14	at 20	= 280
3d Wort	14	at 6	= 84
	40	at 19.6 av.	= 784

Here we have forty barrels of wort, which, if all mixed, would average 19.6 lbs. per barrel. This would be too weak for ale, and too strong for small beer. Let the worts, therefore,

be mixed up in other proportions, such as the following:—

	Barrels.	lb. gravity.	
1st Wort	12	at 35	= 420
2d Wort	7	at 20	= 140
Strong Ale	19	at 29.4	= 560
There now remains of			
2d Wort	7	at 20	= 140
3d Wort	14	at 6	= 84
Making	21	at 10.6	= 422

which would be saleable small beer. Should we wish it, we might improve the quality of both, in this, or some similar manner:—

	Barrels.	lb. gravity.	
1st Wort	12	at 35	= 420
2d Wort	2	at 20	= 40
Strong Ale	14	at 32.8	= 460
There remains of			
2d Wort	12	at 20	= 240
3d Wort	14	at 6	= 84
Being	26	at 12.4	= 324

which is a good strength for small beer.

Other combinations might be made according to the sort of article that is required. Some brewers, for instance, might divide their worts in the following way:—

	Barrels.	lb. gravity.	
1st Wort	12	at 35	= 420
2d Wort	14	at 20	= 280
Strong Ale	26	at 26.9	= 700
and 3d Wort	14	at 6	= 84

for small beer. The strong ale, at nearly 27 lbs. gravity per barrel, is of the usual strength at which the London brewers make their sixty shillings ale, but those in the country will probably be surprised at the mention of 6 lbs. small beer. Persons who *wonder* know nothing of the metropolis. This strength would make very fair workhouse beer—fully as good as the price can afford. The excise duty is two shillings, and we have, nevertheless, known contracts for supplying some of those establishments, to which the beer was driven for miles and delivered at six shillings a barrel!

§ 3.—*Of making up Lengths.*

The necessity of boiling a wort longer than is otherwise requisite, for the purpose of raising its gravity, should be always guarded against, and seldom happens with experienced brewers. These can regulate their mashes so as

to ensure the intended quantity and strength; but cases will occur, from various unforeseen circumstances, such as a mistake in the quality of the malt, where they must have recourse to a more than ordinary evaporation. In such cases, the saccharometer is the only guide. As an example, we shall suppose a brewing of porter, which, in London, is always made of an entire gyle, and, as nearly as possible, of the same strength. Let there be ten quarters of malt, from which the brewer expects 80 lbs. per quarter:—Of the black (or patent) malt, we take no account. The gravity of our porter must not be under 21 lbs., if we would keep up the character of the house. We have already cast the first and second worts, and the third is in the copper. A mash stands on the goods for a *Return*, but this can be of no service in the case before us:—We have, in the coolers,

Barrels.		lbs. Gravity.	
1st Wort	12.5	at 32.5	= 406.2
2d Wort	13	at 20	= 260
Making 25.5 in weight			= 666.2

The third mash in the copper (allowing for the heat according to the Tables of Expansion which accompany the saccharometer) would, if cast now, amount to 16 barrels at 5 lbs. per barrel, being 80 lbs., the whole value of what remains in the copper. Adding this to the 666 lbs. already in the coolers, we find that the whole of the extract from the goods amounts only to 746 lbs. in place of the 800 lbs. which was expected. These 746 lbs. must be divided into barrels of 21 lbs. each; and, therefore, dividing by 21, we find that the quotient (35.5) is the whole quantity (*length* the brewers call it) which can be produced from this *gyle*. On looking back, we find that there are already 25½ of those barrels in the coolers; so that what worts are in the copper must be boiled down until, when cold, they shall not measure more than ten. There are 80 lbs. weight in the copper, and when boiled to 10 barrels, the gravity will be 8 lbs., for the evaporation is wholly aqueous. Suppose the operation finished, and we shall have—

Barrels.		lbs. gravity.	
1st Wort	12.5	at 32.5	= 406.2
2d Wort	13	at 20	= 260
3d Wort	10	at 8	= 80
35.5		at 21	= 746.2

In the preceding statement, we have mentioned a *Return*, without explaining the term. It was because we shall afterwards have to give directions on the subject. In the meantime we may state, generally, that it is a washing of the *goods*, which forms no part of the brewing of that day; but is preserved, with what strength it possesses, to be used as mashing liquor for the succeeding brewing.

CHAPTER VI.

Of the Materials of Ale and Beer.

At the present time, *ale* and *beer*, according to the will of the brewer, approach or recede from one another in their composition and consequent qualities, and are definable only in their extremes. We have reason to believe that our ancestors made a complete distinction: that, with them, *ale* was the pure wine of the malt, and that *beer* was *that* wine mixed with hops, or other bitter ingredients. In the improved edition of the "*Maison Rustique*," which was published in 1616, under the care of the industrious Gervase Markham, there are some useful remarks under the head of "*Brew-house*." Among many other things, he says that "the generall vse is by no means to put any *hops* into *ale*: making that the difference betwixt it and *beere*, that the one hath *hops*, the other none: but the wiser huswives do find an error in that opinion, and say the vtter want of hops is the reason why ale lasteth so little a time, but either dyeth or soureth, and therefore they will to euery barrell of the best ale allow halfe a pound of good hops."

According to the present law, ale or beer, made for sale, must be composed entirely of malt and hops. Water is no doubt understood; but the qualities of the various kinds of those ingredients are left undetermined. We shall say something of each.

§ 1.—*Of Water.*

Pure water, although not a simple substance, is invariably the same; but it must be observed that the brewer never works with water that is pure: it is very unlikely that it would answer his purpose. If the saccharometer be made so as to sink to a certain point marked *zero* (a cypher) in distilled water, it will be found that every other liquor which

he can employ will show an infusion of something that marks, on his scale, a certain weight per barrel. What that something is he may not know; but as it appears in certain springs to the extent of a pound per barrel, it may, for aught he knows, have a material effect upon the result of his process. Further, the prohibitions of the Legislature are hereby often put at defiance, or thrown into ridicule; for, while the Excise-officer shall be threatening, or prosecuting, one brewer for putting a quarter of an ounce of sulphate of iron (copperas) into a barrel of his porter, another brewer, under the survey of the same officer, shall have ten times that quantity dissolved, naturally, in the water which supplies his brew-house. It is the same with carbonate of lime, common salt, and many other articles, which are strictly prohibited.

The carbonates of lime, magnesia, and potash, are powerful correctors of acidity, that plague of the brewery; but these are more frequent in *well* than in *river* water. The latter, especially that which comes from marshy grounds, is seldom to be chosen. The month of October, so famous from time immemorial for the manufacture of English beer, is that in which river water is most generally unfitted for use. It is then loaded with vegetable decompositions, and living animalculæ, neither of which are favourable to the vinous fermentation. The choice of water, therefore, if he be fortunate enough to have a choice, is a matter for serious consideration. Any solution that would affect the flavour of the ale will show itself in the taste of the water, which is then to be avoided without troubling ourselves with the analysis; but if there be nothing disagreeable either in taste, colour, or smell, and yet, notwithstanding, its specific gravity be markedly superior to that of distilled water, it is well to know what substance, or substances, it contains.

There have been, in all times, a contrariety of opinions among brewers concerning the adoption of *hard* or of *soft* water. *Hard water* is a term derived from culinary operations. It is such water as does not dissolve soap, and which is also ill-fitted for the extraction of the virtues of tea. *Soft water*, on the contrary, has both these qualities. Hard water is chiefly drawn from pit-wells. That which is the hardest contains sulphate of lime, which, by a

double decomposition, separates the materials of the soap. With regard to its extractive power, this will probably depend upon the nature of the extract. In its application to malt, we have not discovered any deficiency in the quantity of produce. With regard to its effects on the beer, the sulphate of lime is not suspected to be in the slightest degree deleterious, and otherwise it is believed to be a preservative.

Another species of hard water is caused by the admixture of carbonate of lime, which is held in solution by means of an extra portion of carbonic acid. This is, however, less hard than the former; for it becomes *soft* by long boiling: the overplus carbonic acid is dissipated by the heat, and the pure carbonate of lime, being no longer soluble, is precipitated. It forms the incrustations that are so frequently seen on the insides of tea-kettles and other boilers. Whether this lime should be so precipitated before the liquor is used for mashing, has been much doubted by those brewers who have thought at all upon the subject. Lime is a favourite in the brewhouse. It is openly used, mixed with water, to preserve their wooden vessels from acidity, while they are unemployed in the summer months; and it is often put, by stealth, in the form of *marble dust*, *crabs' claws*, *egg shells*, &c., into their spring-brewed ales, for the purpose of absorbing the first germs of the acid fermentation.

§ 2.—Of Malt.

The juice of the grape, the sugarcane, and many other vegetable substances, contain a great proportion of a sweet, or saccharine matter, ready formed; but the farinæ (or meal) of the common grains require to undergo some sort of operation before they become sweet. The process by which the grain acquires this taste, and which fits it for the use of the brewer, is termed *malting*. The barley, or other grain, becomes *malt*; that is, it is *mellowed*, or *sweetened*, so as to taste something like what the Latins called *mel*, and we term *honey*.

The ordinary process of malting is that of vegetation. The grain is first steeped in water until it has imbibed the moisture to its centre, and then spread on a floor, and turned from time to time, in quantities of various depths, according to the state of vegetation, which immediately commences. At a certain

stage of the growth, the grain (which has been gradually becoming sweet) has acquired its maximum of *saccharification*. This, in barley, ordinarily occurs in two or three weeks, and is judged to take place at the moment when the *acrospire*, or rudiment of the future stalk, is ready to burst the shell. In other grain, the criterion is different; but we are not now writing a treatise upon *Malting*, although such a work is certainly wanted. The malt having arrived at this stage, is dried on a kiln, at a low, or a high heat, according as it is wanted to be pale, amber, or brown. Pale malt may be, and usually is, dried upon a hair-cloth, spread over wooden spars; but amber-coloured and brown malt require the floor of the kiln to be of iron-wire, or of perforated tiles. In either case, it is dried by means of the heated air passing through the malt and carrying the moisture along with it; and, therefore, when the empyreumatic flavour is guarded against, the fuel consists solely of coke, or other charcoal. In the case of amber, or brown malt, this care is not wanted, and hence the fire is made partially, if not wholly, of wood. The pyroligneous acid would thus pass through the malt; and there was once a time when the flavour so conveyed was supposed to be necessary to porter, for which those sorts of malt were solely manufactured. At the present time, porter for ordinary consumption is made wholly from pale malt; and a certain portion of *Patent Malt* (which is malt roasted like coffee, until it is black) is added for no other purpose but to produce the requisite colour.

This *conversion* of the mealy part of the grain into a sweet substance, or *saccharum*, and which has been called by some chemists the *Saccharine fermentation*, may be produced in a much more rapid manner than by the ordinary process of malting. If the grain be reduced to meal, in the manner stated under the section "*Grinding Machines*," and infused in water in the mash-tun (mixed up with a relatively small portion of ground malt); and if this infusion be kept for two or three hours, according to circumstances, at a heat of 150°, or nearly so, the whole mash will become saccharine: the fecula of the grain being as completely malted as if it had lain a fortnight on the malting floor. The proportion of malt is introduced as a *nidus* to hasten this fer-

mentation, on a similar principle as we put yeast into the worts which we would ferment into beer; or a portion of the *mother water* when we would turn the beer, or ale, into vinegar. The particulars of this manipulation will be given when we speak of the process of saccharification, or of brewing from unmalted grain.

§ 3.—Of Hops.

The general opinion of brewers, as well as of the public, is, that hops were first used in beer for the purpose of preserving it from acidity. This we doubt. Bitter ingredients, of various kinds, were used by our forefathers, before hops were considered proper for the purpose; and even the time is not very distant when these were supposed to be poisonous, and on that account prohibited by the legislator. We believe that, long ago, ale was made from malt alone; and that, when there was any fear for its preservation, a little honey was mixed with it, as is done at present in the South of France. The Herbalists, who were the *leeches* of those times, recommended certain plants as proper to be infused in the malt liquor, which was then termed *herb ale*: a denomination still known in various parts of the island. These herbs, like the medicaments of our own days, were generally the bitterest and most nauseous that could be found; but they cured diseases, and were, therefore, not only tolerated, but sought after; and, in process of time, some of them became necessary to certain tastes, and exist in the beer, or porter, which we now drink. Wine itself, when prescribed by the physician, is often medicated, serving as a vehicle for the introduction of the extracts of wormwood, quassia, gentian, and other bitter plants which, before their prohibition, were common in the brewhouse.

The culture of the hop is too well known to need any particular description in this place. There is only one species (*humulus lupulus*); but it has many varieties, which are chosen by the cultivators according as they are supposed to be most suited to the climate and soil. The plant is diœcious, and it is the female catkin which is picked and preserved for the brewer. Hops are strongly narcotic; but their bitter principle is the ostensible reason for their infusion in malt liquors.

The finer-flavoured and light-coloured

hops are pressed into sacks of comparatively fine cloth, called pockets, which weigh about a hundred weight and a half each, and are sold chiefly to the ale-brewer. The strong-flavoured and high-coloured hops are put into bags of a very coarse *mat-kind* of texture, called bags, and contain, generally, double the weight of the pockets. These are used by porter and small-beer brewers.

The bitter principle of hops is probably the same in all its varieties and modes of cultivation; but, in conjunction with this bitter, there is always, in new hops, a communicable flavour, or rather *aroma*, by which their several qualities are distinguished. Ale-brewers talk much of this *aroma*, and speak of its being concentrated in the essential oil of the hop, without considering that it must be, in a great degree, evaporated during the boiling of the worts. This *aroma*, like all others, is extremely evanescent. One of the best modes of preserving hops is to bury them among the dry malt; but, do what we will, the fine flavour does not exist a twelve-month. Beyond that time they become *old hops*; and are sold at a cheaper rate to the porter-brewer. A year or two longer, and the *bitter itself* disappears; and the whole becomes nothing better than chaff. The same deterioration takes place when infused in the beer. The flavour is but of momentary duration; and the *bitter principle* gradually decays. In favour of those who believe that this bitter prevents acidity, it has been stated that the bitter is lost in proportion as the acidity is advanced. The loss of the one and the accession of the other are both, generally, the consequence of age; and it is well known that nothing is more easy than to mistake a concomitant circumstance for a cause. Thirty years ago, when we were young in the observance of the brewery, we formed a theory,—that the *bitter principle* was a substance *sui generis*, which, (while it lasted) by some chemical affinity, absorbed the acetous acid, gradually as it was formed. Subsequent experience has given us reason to suspect that this hypothesis is a dream.

It is the ale-brewer only who seeks for peculiarity of flavour in his hops. It is he who discriminates with nicety on the produce of the several counties; but his judgment varies with the taste of his customer. With respect to taste

there is no criterion. It depends almost wholly on habit, otherwise we should find very few that could have a pleasure in chewing tobacco. The flavours of the different sorts of ale, however they are produced, are almost as various as the species of continental wines. The Burton, Wiltshire, Scotch, and London ales have little resemblance to one another, but each has its admirers. To be sure those varieties do not altogether depend upon the quality or quantity of the hops; but the infusion of this plant has always its share in the composition.

We believe that we cannot better conclude this section than by an extract from Mr. Richardson's work, formerly mentioned, which, though written thirty years ago, is not inapplicable to this present time:—

“The difference of soil has certainly a considerable influence in producing the real difference in flavour observable in hops. Those which grow on the stiff clays of Nottinghamshire, and are thence termed *North-clay hops*, have the pre-eminence in *rankness*, and accordingly, with a certain description of buyers, bear a higher price than Kent, though that is not so high as the general price of Farnham hops. To those who are not accustomed to the flavour of North-clay hops, they are undoubtedly rank, bordering on the nauseous, particularly whilst the beer brewed from them is new; and, indeed, that rankness generally remains a very considerable time, if not concealed by an abundant extract of malt. Hence they appear better adapted to strong-keeping beers, than to any other kind of malt-liquor.

“Farnham hops, however deserving the reputation they bear, are by no means worth the difference in price generally given for them, to a brewer, except the vicinity of his residence may, in some measure, lessen that difference; and it is not the intention of these pages to *appreciate* their value to the private consumer, with whom, perhaps, the idea of their incalculable excellence may have originated.

“The county of Kent, though justly claiming pre-eminent distinction in the produce of its hops, considered as uniting flavour with strength, is far from being uniform in its general priority, in this respect; for different parts produce different qualities, varying with the soil,

or some other local circumstance, and all yielding the palm of superiority to those which grow in the neighbourhood of Canterbury.

"If, however, the rank austerity of the North-clay hops excites a nausea on the palate accustomed to the milder flavour of the Kentish, these, again, are as little relished by people who are in the habit of drinking ale in which Worcester hops only have been used. The flavour of these has a grateful mildness in it, not to be met with in any other hops. Hence the finest growths of Kent, in Lancashire, Cheshire, and some other counties, where the use of Worcester hops prevails, would be rejected as unsaleable; and so great is the objection of some of the inhabitants of those counties to the flavour of Kent hops, that I have heard them distinguish ale bittered with the latter, by the name of *Porter-ale*. Indeed, the distinction has propriety in it, so far as the strength of a large portion of these may convey to some palates the idea of *porter*, and that the mildness of the former can hardly be applicable to any liquor but *ale*."

§ 4.—Of Isinglass.

Although isinglass is not properly one of the materials of beer, being deposited as soon as it has performed its office of *fining*, yet, from its frequent employment and being the only ingredient that can be *legally* introduced into malt-liquor, we deem it not out of place in the present chapter.

"Fish-glue, as it is improperly called, is generally known by the name of *Isinglass*, a word corrupted from the Dutch *Hyzenblas*, an air-bladder, compounded of *hyzen*, to hoist, and *blas*, a bladder."

"It is chiefly prepared in the vicinity of the Caspian and Black Seas, from the *sounds*, or *swims*, of different species of the *acipenser*, or sturgeon. These bladders, stript of their outer rind and dried, constitute the isinglass of commerce. The skins, tails, &c., of these and other fishes are used for the inferior sorts of isinglass, but in no case are the materials boiled; for that would invariably convert them into glue, an article that has different qualities from those for which isinglass is required. Much of the latter, for instance, is used in making *Finings*, for the clarification of malt-liquors; whereas glue, added to turbid

beer, would increase both its muddiness and its tenacity."*

In the brewery, isinglass is used solely as *finings*, that is, to clarify beer that is foul and muddy. In ale it is seldom necessary; but in porter, as commonly brewed, it cannot be dispensed with. Those sorts which are termed *long* and *short staple* (made from the larger and smaller fish respectively) being composed of single membranes that run parallel to each other, and are separable by infusion in cold water, are less liable to putrefaction; but the *Book-isinglass*, so called because it is folded somewhat in the shape of a book, is often found to be spoilt in its folds, from imperfect drying, which allows the generating of maggots, and consequent putrefaction. These spoilt parts should be carefully thrown aside.

The manufacture of isinglass was long exclusively confined to certain Russian provinces. In 1763 a patent was granted to a Mr. Jackson, for the preparation of "British isinglass," which was to be made from what he called "British materials"—but in reality from the entrails of sturgeons and other fish, imported from the American colonies, or caught on our own coasts. This undertaking was unsuccessful; for, in a well-written "Essay on British Isinglass," which Mr. Jackson published in 1765, he complains, that of 25 tons annually consumed in the brewery, he had only supplied a fourth, on account of certain prejudices that were raised against his article. These prejudices, however, no longer exist; for many of the large breweries now make use of nothing but the dried skins of soles.

Whatever sort of isinglass he employs, the brewer prepares his *finings* in the same manner:

It may be observed, that a pound of good isinglass will make about 12 gallons of the preparation. It may be used whole, but, for the sake of expedition, it is often bruised and pulled in pieces; then being put into a tub, with as much common vinegar as will cover it (or the same quantity of beer of any kind, which has acquired a considerable degree of acidity) the isinglass will swell and dissolve. As the whole thickens, there should be more beer added to it, and that of inferior acidity, because when the stronger acid has dissolved the isin-

* Booth's Analytical Dictionary of the English Language.

glass, almost any beer will serve to dilute and prepare it. This solution should be frequently stirred about briskly with an old stump broom, which separates the undissolved parts and makes it all of one consistence, which, finally, should be that of thin treacle. This is to be whisked through a hair sieve, or squeezed through a coarse linen cloth, into another tub, previous to using it. The quantity to be used is from a pint to a quart per barrel, according to the degree of feculency in the beer. This should be made quite thin with some of the beer intended to be purified, whisking it up till it froths. It is then to be poured into the cask, and stirred briskly about in it, bunging it down immediately, and the beer will become pure in about 24 hours, provided it has been in a condition proper to receive the finings.

An eligible mode of discovering whether beer be in a proper state to yield to finings or not is the following:—

“Draw off a little of the beer into a pint, or half-pint phial, and add to it about half a tea-spoonful of the finings. Shake it up, and then let it remain stationary. If the finings will have the desired effect, you will observe, in a few minutes, the isinglass collecting the feculencies of the beer into large fleecy masses, which will begin regularly to subside to the bottom. If the beer be not in a proper state, (which is ever the case as long as the fermentation continues, or an after *fret* prevails,) the bulk of the finings will soon be at the bottom, leaving the beer neither pure nor foul, except just at the top, where there will be a little transparency, perhaps a quarter of an inch deep, which will grow deeper in time, but will not readily extend to the whole.”

The mode in which isinglass acts upon the feculencies of beer has been variously estimated. The general idea is, that it spreads over the surface of the liquor, and then falling by its weight, carries down the foul parts, allowing the pure beer to ascend, as if strained through a sieve. On the contrary, it seems to us that its effect is owing to that indescribable cause termed chemical attraction. The observations of Mr. Jackson, formerly mentioned, lead directly to this result. According to him, isinglass is never *perfectly* dissolved in the acid liquor, otherwise it would cease to act as *finings*. These, however inti-

mately mixed with any dissolvent, must always preserve a fibrous form; for says he, “Any substance which appears horny, breaks short, or snaps like glue, although it dissolves like isinglass, and puts on the appearance of a rich thick jelly, the universal characteristic of good fining, yet will not fine down beer.” The isinglass and the acid beer are then only mechanically, not chemically united. If the latter, they would become a species of glue; and such, finings will become, if exposed even to a very moderate degree of heat, perhaps at 90° or 100°. They should, therefore, be kept cool. “That common finings,” says the same author, “is nothing more than a due division, or an imperfect solution of isinglass in subacid liquors, may be proved, by viewing it through magnifying glasses, or by admixing a few drops of fining with fair water in a glass, which being held up to the light, the fibres may be seen swimming in an infinite variety of forms and sizes, and, on subsiding, arrange themselves according to their different gravities, the smallest particles of which, perceptible to the eye, attract each other, and form an appearance of little clouds. If then we take this mixture, and warm it at the fire, we shall presently find, that all these fibres will escape perception, in being perfectly dissolved, except a few gross parts. The same phenomena appear, if we place a little fining near the fire, or hold a lump a few minutes in the palm of the hand; *thus the consti-
tution will be broken, the fibres dissolved,
and the efficacy destroyed.*”

The rationale of the action of finings, according to the author just quoted, is this:—“It is evident that at the very instant that fining is commixed with beer to be clarified, the stale beer, in which the isinglass was dissolved, or divided, quits the fibres and unites with the body of the beer; while at the same time the fibres, now set loose, and everywhere interspersed in the beer, attract and unite with the loose feculent particles, which, before this union, being of the same specific gravity with the beer, could not possibly subside alone, but by this reciprocal attraction having obtained an additional weight, are now rendered proportionably heavier, and precipitate together of course, in form of the curdly magma just mentioned. But it sometimes happens, from certain inadvertencies in brewing, and mismanage-

ment in the cellar afterwards, that beer turns out specifically heavier than the fibres of the isinglass; in which case the fining cannot subside, for the reasons aforesaid, but floats at the surface: at other times, notwithstanding the union of the fibres and feculencies, the combined matter becoming exactly of the same weight as the beer, continues interspersed everywhere in it, and neither emerges nor subsides; in both instances the beer is nicknamed *stub-born* by the coopers."

CHAPTER VII.

Of Illegal Ingredients.

ALTHOUGH water, malt, hops, and isinglass are the only materials which can be legally employed in the manufacture of malt-liquors, brewed for sale, yet, as the prohibitory clause is but of modern date, and many other articles have been wont, from time immemorial, to be added to beer, which are not only innocuous, but occasionally advantageous, and are still left to the discretion of the private brewer, we have judged it proper to class them together in the present chapter. In doing so, we shall distribute those which have been most commonly used into five divisions:—

1. Such ingredients as are intended to increase the quantity of saccharine matter, or strength of the worts; and, consequently, to save malt.
2. Such ingredients as are intended to increase the quantity of the bitter principle; and, consequently, to save hops.
3. Such ingredients as are intended to prevent the introduction of acidity; or to diminish or destroy that acidity when it is already formed.
4. Such ingredients as are intended to add an extraneous flavour to ale, or beer, so as to accommodate it to the taste of the inhabitants of any particular district, who have been accustomed to that flavour. And,
5. Such ingredients as are intended solely for the purpose of increasing the intoxicating quality of ale, or beer, and which are, in almost all cases, of too poisonous a nature to be introduced with safety.

On the principal articles in each of these divisions we shall make a few remarks, and then leave their introduc-

tion, or rejection, to the judgment of the brewer: premising, in the outset, that various and very different flavours may be given, in the process of fermentation, to ale which is manufactured from malt and hops alone.

§ 1.—*Of Ingredients which are intended to increase the quantity of Saccharine Matter, or Strength of the Worts.*

Of all the substitutes for malt, raw grain is the principal—if, indeed, that can be called a substitute which is merely malted in the mash-tun in place of the floor. The process by which the conversion of barley, or other grain, into malt is thus rapidly performed will be detailed in a subsequent chapter. While we warn the public brewer of the *legal* danger of its adoption, we would strenuously recommend its use in private families. Were the practice to become general, a deduction of the duties on beer made for sale would inevitably follow.

Pure sugar and water (it has been said) will not ferment; but raw sugar, or molasses, will make very good beer either alone, or mixed with malt-worts. There is, however, no saving from the use of these materials, unless when malt becomes much dearer than in ordinary years: in which case they are occasionally permitted to be used under the authority of the Lords of the Treasury. A weak beer from molasses is frequently made in private families, and drunk in a half-fermented state; but it is too luscious for the taste of those who are accustomed to the small beer of malt. Molasses, mixed with a weak malt-wort, would, when fermented, be much more palatable.

Our ancestors, as well as other northern nations, were much accustomed to a vinous liquor from honey, which vied with the wines of the south: the *methu* of the Greeks, the *medu* of the Saxons, the *hydromel* of the Latins, and the *mead*, or *metheglin*, of more modern times. The extension of agriculture, which by diminishing the food of bees raised the price of honey, conjoined with the excise-duty imposed, has completely annihilated the manufacture of mead for sale, and even in private families it is now seldom or never to be seen. Honey, however, is still used in the private brewing of ale; and in some districts it is clandestinely introduced by the public brewer. The design and effect of this introduction will be after-

wards explained. It is almost unnecessary to add that honey is not deleterious.

Liquorice root, (Glycyrrhiza glabra,) both in powder and in the state of extract (*Spanish juice*), was formerly an essential constituent of malt-liquors, and particularly of porter. We believe, however, that the saving of malt was less considered in this article than its flavour. At all events the introduction in the copper of about half-a-pound per barrel, and that quantity was seldom exceeded, must have been perfectly harmless.

§ 2.—*Of Ingredients which are intended to increase the quantity of the bitter principle, and in consequence to save hops.*

That hops prevent ale from becoming acid is, if true, a comparatively modern discovery. Mum, (a malt-liquor now unknown in England,) although directed to be kept two years before it was tapped, contained no species of bitter among its numerous ingredients; and the beer of Louvain, so famous throughout France, is brewed without hops. It is well-known that bitter infusions themselves, without any other vegetable matter, will become sour.

The use of bitters followed the advice of the physician, who, being anciently a herbalist, recommended the plants that grew in his garden. Each plant had its particular disease which it was able to combat; and hence the whole science of medical botany. According to those gentlemen, the bitter principle was, and still is, peculiarly efficacious. "It is a pure tonic,—increases the appetite,—promotes digestion,—gives vigour to the system, &c." Unfortunately for this general eulogium, the bitters are either different in their essence, or they are never pure. A few, such as gentian and quassia, are, comparatively, inactive. Some, like aloes and marsh trefoil, are purgative. Hops are astringent and narcotic; broom and some others are diuretics: while many, as opium, cocculus indicus, ignatia amara, tobacco and nux vomica, are highly poisonous. Yet each of those here mentioned, and others which we have not named, have been boiled among the worts of beer, without regard to their effect on particular constitutions, or to the general safety of the individuals for whom the liquor is brewed.

These observations being premised, our account of the substitutes for hops may be short. Broom, wormwood, and several other bitters, are now almost universally laid aside; for, since the flavour of the hops has been so generally recognized, no bitter which is inconsistent with that flavour would be relished. Bitters that are perfectly, or at least nearly, flavourless may, indeed, be added to hops when the bitter principle only is required; and this is the case with porter, in which *flavour is little studied*: for the hops usually employed in brewing that beverage are either coarse, or old, and would not be admissible in fine ales. The cocculus indicus, so frequently introduced into the latter, has a taste by no means agreeable; but its intoxicating quality is all that is wanted by the brewer, and, could that be procured (as has been attempted) in an isolated state, its flavour would be willingly dispensed with.

The bitter contained in porter is very great, and if taken wholly from hops, must require an average quantity of ten or twelve pounds to the quarter of malt, or about three pounds per barrel. The fluctuation in the price of that article is extreme, as will appear from the following statement, which was printed in 1819, by order of the House of Commons. The quality here mentioned is *bag hops*, which are the cheapest in the market.

1789 Oct.	6 <i>l.</i> 14 <i>s.</i>	to	7 <i>l.</i> 2 <i>s.</i>	per cwt.
1790 Oct.	76 <i>s.</i>	—	84 <i>s.</i>	—
1791 Oct.	5 <i>l.</i> 5 <i>s.</i>	—	5 <i>l.</i> 12 <i>s.</i>	—
1792 Oct.	80 <i>s.</i>	—	84 <i>s.</i>	—
1793 Oct.	9 <i>l.</i> 9 <i>s.</i>	—	10 <i>l.</i> 0 <i>s.</i>	—
1794 Oct.	84 <i>s.</i>	—	—	—
1795 Oct.	5 <i>l.</i> 0 <i>s.</i>	—	5 <i>l.</i> 12 <i>s.</i>	—
1796 Oct.	80 <i>s.</i>	—	84 <i>s.</i>	—
1797 Mar.	112 <i>s.</i>	—	120 <i>s.</i>	—
1797 Oct.	84 <i>s.</i>	—	90 <i>s.</i>	—
1798 Oct.	9 <i>l.</i> 9 <i>s.</i>	—	10 <i>l.</i> 0 <i>s.</i>	—
1799 Nov.	14 <i>l.</i> 14 <i>s.</i>	—	—	—
1801 Jan.	16 <i>l.</i> 5 <i>s.</i>	—	18 <i>l.</i> 0 <i>s.</i>	—
1802 Jan.	5 <i>l.</i> 5 <i>s.</i>	—	—	—
1803 July	5 <i>l.</i> 12 <i>s.</i>	—	—	—
1804 July	4 <i>l.</i> 15 <i>s.</i>	—	5 <i>l.</i> 0 <i>s.</i>	—
1812 Nov.	13 <i>l.</i> 13 <i>s.</i>	—	15 <i>l.</i> 5 <i>s.</i>	—
1813 Jan.	13 <i>l.</i> 13 <i>s.</i>	—	15 <i>l.</i> 10 <i>s.</i>	—
1814 Dec.	9 <i>l.</i> 4 <i>s.</i>	—	9 <i>l.</i> 9 <i>s.</i>	—
1815 Feb.	8 <i>l.</i> 16 <i>s.</i>	—	9 <i>l.</i> 9 <i>s.</i>	—
1816 July	6 <i>l.</i> 10 <i>s.</i>	—	6 <i>l.</i> 17 <i>l.</i>	—
1816 Oct.	14 <i>l.</i> 14 <i>s.</i>	—	—	—
1817 Jan.	14 <i>l.</i> 5 <i>s.</i>	—	—	—
1818 Jan.	31 <i>l.</i> 0 <i>s.</i>	—	—	—

It is not to be wondered at, that, under these circumstances, substitutes

should have been sought for with avidity. If the substitutes were not more noxious than the principal, (and some of them were less so,) the conscience of the brewer was easily satisfied: especially seeing that he could procure as much bitter for sixpence as would otherwise have cost him a pound.

Marsh trefoil, *buckbean*, or *bogbean* (*Menyanthes trifoliata*), has been employed in place of hops,—openly on the continent, and privately, (at one time,) as has been said, in this country. The leaves were collected, when mature, and dried in the shade, to preserve their colour. They were then well boiled and scummed to free them from their extract of roughness; and the remaining extract was preserved and put into the fermenting tun in such proportions as the brewer judged proper, or as his druggist chose to direct. These leaves have very nearly the flavour of the hop; and an ounce of the former is said to be equivalent to half-a-pound of the latter. It should be observed, however, for the guidance of any one who shall dare to use them, that although they stand recommended in the modern pharmacopœias, the quantity of a drachm taken in powder “purges and vomits.”

Aloes (the dried juice of the *ALOE perfoliata*) is a well known bitter, being much used in medicine. When it was allowed to be sold to brewers, the variety *succotrina* was always preferred, as having the least objectionable smell. The quantity which could be mixed with the hops in the copper was limited, in consequence of its purgative quality, and seldom exceeded half an ounce to a barrel of porter.

Quassia is another well-known bitter; it is the favourite of the physician, and would be equally so of the porter-brewer, if he dared to use and acknowledge it. The smell, if any, is imperceptible, and the bitter is intense, pure, and lasting. The *quassia amara* (a shrub) is the most biting of the tribe; but that commonly imported into this country, from the West Indies, is the bark and wood of the root and trunk of the *quassia excelsa*, which is a large tree. When the porter-brewers made use of quassia, it was either in small chips or rasped, and put into the copper (with the hops) in a quantity of about an ounce to the barrel. This is, probably, the most harmless of all the illegal bitters. The physicians prescribe the decoction to

their patients to the extent of a quarter of an ounce of the bark a day,—as much as the brewer was accustomed to put into nine gallons of his porter.

There are other bitter ingredients worth noticing; but as they are intended for purposes different from the saving of hops, they belong more properly to the succeeding divisions of this chapter.

§ 3.—*Of Ingredients which are intended to prevent the introduction of acidity, or to diminish or destroy that acidity when it is already formed.*

It would not be difficult to account for the action of the greater number of the ingredients of this description, upon the principles of modern chemistry. Nevertheless, it is certain that all those articles were in use, for the same purpose, centuries before the present theories of acetification had existence. Practice always precedes theory. The latter merely strings together the facts that have been previously (often accidentally) discovered. It was known, from time immemorial, that ale, or beer, when exposed to the atmosphere, especially in summer, became rapidly sour; and hence the closeness of the casks, and the coolness of the cellars, were as much attended to in former as in latter times. It was also known that certain salts, (as they were called,) and certain earths, were preventives if not remedies: in short, we know little or nothing that is new upon the subject.

Common salt, so useful in preventing the putrefaction of animal substances, was also believed to have a similar effect in the preservation of vegetables; and, accordingly, we find the condemnation of its use among the earliest restrictive laws of the brewery. Different opinions exist with respect to its utility; but, however these may be decided, it can scarcely be suspected to be dangerous. Publicans have been accused of putting it in the beer to produce thirst; and we have known private gentlemen, who prided themselves on the quality of their *home-brewed*, throw in about a pound per barrel into the casks with the view of flavour. Many brewers mix salt with wheat or bean flour, putting a handful in each cask before cleansing, to promote the discharge of the yeast; and, occasionally, the same mixture of flour and salt, or flour and *saltpetre*, or *salt prunella*, is introduced into the tun to rouse a languid fermentation.

That the fermentation should not linger between a nauseous sweet and a vinous flavour, is reckoned essential to the prevention of acidity. The extent to which it should be carried will be considered hereafter, but we now speak of such ingredients as are supposed to excite the working when it is too languid. *Jalap*, to the extent of two, or even three ounces, to twenty barrels, is employed by certain brewers in the gyle-tun, but the *rationale* of its action is to us unknown.

The formation of vinegar, like other fermentations, proceeds more rapidly when it has a *nidus* or incipient acidity from which to begin. In the aerial theory, that *nidus* is oxygen; and to destroy or counteract this oxygen in the outset is to strangle the demon in the moment of its birth.

When the fermentation is finished in a proper manner, it remains with the brewer to keep the casks, if possible, hermetically sealed, to prevent the admission of the external air. Bottles are still better than casks. When laid on their sides, so as to keep the corks swelled, nothing can enter from without; and the sole danger is, when the liquor retains so much of undecomposed saccharine matter as to cause the bursting of the vessel from a new fermentation. It is on this account that beer, when it is to be bottled, is usually exposed for a time to the atmosphere, by loosening the bung, in order to *flatten* it; that is, to facilitate the escape of the carbonic acid which it then contains. During this exposure, while the fixed air escapes, a portion of the atmospheric air may enter; and with the view of preventing this, it is the practice of some, who affect the mysteries of the trade, to pour about two ounces of the *spirit of Maranta* into the cask, which is then allowed to stand, without the bung, for three or four days before bottling. How this can exclude one gas and allow another to escape, we know not, having never personally made the experiment. This fiery liquid is a spirituous extract of the medicinal root *Galangal*:—the *Kœmpferia galanga*, *Alpinia galanga*, *Amomum galanga*, and *Maranta galanga*, of different botanists.

The exclusion of the atmospheric air, by covering the surface of the liquid, has been managed in different ways. The small wine, when carried out to the Italian vintagers, is in weak flasks,

which would not bear the pressure of a cork. These have long necks, and the surface of the liquor is covered with a film of olive oil, which swims on the fluid, and is easily separated afterwards by means of a little cotton. The handful of half-boiled hops, impregnated with wort, which is usually put into the bung-hole of each cask by the ale-brewer when stowing it in his cellar, answers the same purpose: and some, more rigidly attentive, insert (privately) at the same time, about an ounce of powdered black rosin, previously mixed with beer, which swims on the surface, but after a time is partially absorbed. Of this we shall have again to speak when we treat of *Burton ale*.

Bruised *green Copperas*, called also *salt of steel*, (*sulphate of iron*) which has always been put into porter—formerly by the brewer and now by the publican—is, ostensibly, for the purpose of giving it a *frothy top*. It is either used alone, or mixed with *alum*, and is technically called *heading*. The quantity used need not exceed as much as would lie on a half-crown piece for a barrel, and to that extent there is no danger to be feared. This practice, we believe, had been originally intended to keep the beer alive during the time in which it remained in the pots. The *green sulphate of iron* is greedy of oxygen, and is thereby speedily converted into the *brown*. We apprehend that it is in consequence of this dissolved salt of iron, that certain porter-drinkers have uniformly asserted that there is a peculiar flavour when drinking out of a tin pot, which does not exist when taken from a glass: if this be true, the effect will naturally be referred to galvanic influence.

The brewers, in one quarter of the island, are in the practice of putting sulphate of iron (previously dried to whiteness) in the liquor of their first mash. This is probably meant to guard against that species of acetification termed *blinking*; but its effect must be little, since the quantity is limited to about two ounces for twenty barrels of liquor.

Some ingredients are introduced which lie dormant or deposited in the cask, for the purpose of catching and neutralizing the acetic acid at the moment of its formation. The chief of these is *lime* under various forms. Quick lime does not answer this end. It is partly soluble, and, in so far, communicates a disagreeable taste. The carbonates,

if pure, are free from this fault; and therefore, *marble dust* and powdered *oyster shells* have been generally used. Before any vinegar exists in the beer, these carbonates of lime usually lie at the bottom of the cask inactive; but on the least degree of acetification an acetate of lime is formed and the carbonic acid escapes. The acetate of lime is soluble, and, in proportion as it is formed, the flavour of the beer is altered. It remains, therefore, with the drinker, whether he prefers this new bitterish taste to that of the acetous acid which would otherwise predominate.

We have here supposed that the carbonate of lime will remain inactive until acetous acid shall be formed; but it may possibly be otherwise. An excess of carbonic acid would render it soluble, but the same effect would follow with respect to its union with the vinegar. This soluble super-carbonate of lime, if effected, would not be discernible by the palate; for it often exists plentifully in water without being thus observed. Besides, this extra absorption of carbonic acid would tend to prevent the secondary fermentation, which is the usual precursor of acidity.

Egg-shells and even whole eggs are sometimes introduced into beer, in which they act the same part as the carbonates of lime. The shells are, in fact, almost wholly the same substance. The following *recipe*, which was first published in an early number (the 27th) of the Philosophical Transactions, shows that the use of eggs for the prevention of acidity is of no modern date. The writer (Dr. Stubbs) says that *he learned it from an ale-seller in Deal*, and that he tried it, successfully, in a voyage to Jamaica. "To every runlet of five gallons, after it is placed in the ship not to be stirred any more, put in two new-laid eggs whole, and let them lie in it; in a fortnight, or little more, the whole egg-shells will be dissolved, and the eggs become like wind-eggs, inclosed only in a thin skin; after this the white is preyed on, but the yolks are not touched or corrupted, by which means the ale was so well preserved, that it was found better at Jamaica than at Deal." It may be observed, that although this was new to Dr. Stubbs, he was not the original discoverer. It was probably known in the *trade* for centuries.

Sulphate of lime, which is partly soluble in water, is put into the cask, after it has ceased working, for the purpose

of preventing an *after-fret*. If it effect this end, it is well; but at any rate, the quantity of six ounces to a barrel cannot possibly do harm.

Hartshorn shavings, to the extent of six pounds for twenty barrels, were *formerly* boiled in the worts of the best London ale. These give out *ammonia* by distillation, and consist chiefly of *phosphate of lime*, with a considerable quantity of gelatine. These shavings are probably expected to prevent acidity, but we are at a loss to know how. The ammonia is evaporated, and the phosphate, even were it to act like the carbonate, can scarcely be extracted by boiling.

According to Pliny, the Gauls were able to preserve their beer for many years. We fear that they have lost the secret; but we shall just notice some of the means to which they still have recourse, and which are not practised in this country.

The common Avens, or *Herb Bennet*, (*Geum Urbanum*,) is highly extolled all over the continent, for its medicinal, as well as other valuable properties. It was hence, perhaps, that it acquired the surname of *bennet*, or *benet*, contracted from *benedictus*, although the origin is now ascribed to a Saint of that name. The roots of this plant, particularly when it grows on a dry, sandy soil, have a pleasant odour, (similar to that of cloves,) which it readily imparts to any spirituous menstruum. On this account it is highly valued by the brewers; and is said to be a prominent ingredient in the *Augsburg Beer*, which is so famous throughout Germany. The dried roots are sliced, and inclosed in a thin linen bag, which is suspended in the store-vat, or cask; and it is asserted, with what truth we know not, that the beer so managed never becomes acid.

In former times (and the custom is not yet completely laid aside) the real, or imaginary preventives of acidity were inserted into the cask, along with the *Finings*; or rather, the whole mixture passed generally under the latter denomination. It will be shown, when we speak of the process of *Saccharification*, that the portion of unfermented worts, which always remains in the beer, is often more allied to starch than to sugar; and, in that case, it is frequently the cause,—not only of *foulness*, but of subsequent acidity. On examining the accounts of old processes for the brewing and cellaring of beer, it is curious

to observe their consonance with the chemical announcements of later times. We now know that malt-extract is a mixture of *Starch* and *Saccharum*, and that the former is capable of being deposited by an infusion of *Nutgalls*. The following directions for the manufacture of beer-finings were published in a highly respectable French work, nearly a century ago; and then given as an *old* and general practice among the brewers in Paris:—

Take three pounds of powdered nutgalls and four ounces of potash. Boil these for three hours in such a quantity of water as, at the end of that time, will make the weight of the whole mixture about twelve pounds. To this, when cool, add two pints of spirit of wine; and, after it has settled and become clear, bottle it up for use. Five ounces of this decoction will be sufficient to fine and preserve half a piece of beer.

When the ale or beer becomes really sour, we know not how to extract its oxygen. He who shall discover this will make his fortune. If even the vinegar itself could be deposited, the strength of the remaining beer might be restored; but though the acidity can be neutralized by means of the *sub-carbonates of potash and soda*, which, with other similar articles, are hawked about as *nostrums* among the publicans, the acetous salts still remain dissolved, and contaminate the mass. Attempts are sometimes made to cover the disagreeable taste, by the introduction of *sugarcandy*,—a substance not readily fermentable,—but, even setting aside the trouble and expense, the beer *thus said to be recovered* (although not pernicious) is never pleasing to the drinker.

§ 4.—*Of Ingredients which are intended to add an extraneous Flavour to the Ale or Beer.*

The most agreeable, and, at the same time, the most permanent flavours of malt liquors are those which are formed by the particular modes of fermentation. In addition to these, however, certain extraneous ingredients have been introduced, by individual brewers, which have given a character to their ales; and even whole districts have adopted peculiarities of taste which would by no means pass generally in other quarters. When those ingredients are confined to this single object, their introduction, though legally wrong, is not morally vicious; and we shall, therefore, mention a few

which have been most usually employed.

The dried root of the *sweet flag* (*Acorus calamus*), commonly termed *Calamus aromaticus*, is warm, slightly bitter, and has been extolled beyond all other British plants for its aromatic flavour. This root is usually imported from the Levant, but does not appear to be superior to the growth of our own country.

Coriander seeds (*Coriandrum sativum*) are imported for the use of the brewer, as well as for medicinal purposes. The plant is found wild in this country, but is a doubtful native.

Caraway (the seeds of the *Carum carui*) have also been used in brewing, but not so frequently as the *coriander*, which some believe to add strength as well as flavour. *Caraway* is also found wild in England, and, along with the *coriander*, it is cultivated, in some counties, for the use of confectioners and apothecaries.

The three ingredients last mentioned have, no doubt, been chosen on account of their warm aromatic flavours. All have been boiled together in the copper; the first *sliced*, in the proportion of four pounds to twenty barrels, and the two latter *ground*,—about two pounds each to the same quantity of ale.

Various other stimulating roots and seeds have been made use of: *Orange peel*, powdered, is very generally used by the ale-brewers of this country; as also Orange peas, or Curacao oranges, the unripe fruit of the *Citrus aurantium*. Vegetables of a spicy and more stimulating taste are likewise in general use. Of these, we may mention *Long pepper* (*Piper longum*); *Capsicum*, or *Guinea pepper* (*Capsicum annum*); *Grains of paradise* (*Amomum granum*); common *Ginger* (*Amomum zingiber*), &c. One or all of these foreign seeds and roots are powdered and boiled among the worts, in quantities of about three pounds to twenty barrels: the quantity being regulated by the degree of pungency required.

§ 5.—*Of Ingredients which are intended solely for the purpose of increasing the intoxicating power of Beer or Ale.*

Hitherto we have treated of ingredients which, though illegal, (and, in our opinion, calculated only to gratify an acquired taste,) are at least harmless: but we have now to speak of articles that

deserve no quarter,—of such as are disgraceful to the brewer, because dangerous to the drinker.

The dried fruit of the *Menispermum cocculus*, better known by the names of *India berry* and *Cocculus Indicus*, claims, on account of its very general use, the first place in this infernal list. Its importation into this country (from the East Indies) is very great, considering that few know for what other purpose it is ever used: for, though the *Cissampelos pareira* (which many botanists state to be the same plant) has a place in the pharmacopœias, its virtues are generally referred to the root, and that root is brought from America. That *Cocculus Indicus* is a strong narcotic is doubtless; for it is on that account alone that it has preserved its place in the brewery. In India the berries are thrown into the water for the purpose of catching fish, which, by swallowing them, become intoxicated. They were once used in England in the same way, but, we believe, that practice is now prohibited. Their effects upon the human frame we know not, neither do we wish to know.

The extensive use of this ingredient (and we have good reason to believe that it is still used extensively) was proved to a Committee of the House of Commons in 1818. Those who give brewing receipts recommend it in quantities of four pounds to twenty barrels, boiled with the worts: but there seems to be a mystery on this subject which requires to be investigated.

The *Faba amara*, or *bitter bean*, is the seed of an East India plant, which, though poisonous, has a sanctified name. It is the *Ignatia amara*, *St. Ignatius's bean*, and is not only botanically, but naturally allied to the genus *Strychnos*, a species of which will come next under our review. The *bitter bean* appears in many of the works that pretend to teach the art of Brewing. It is a large pear-shaped berry, with seeds nearly an inch long, and extremely bitter.

Nux vomica (*Strychnos nux vomica*), as described by the botanists, “is the fruit, or rather seed of the fruit, or berry, of a large tree, growing in Egypt, Ceylon, &c. of a strong narcotic quality, so as to be ranked in the number of poisons.” “It is round and flat, about an inch broad and near a quarter of an inch thick,”—“extremely bitter, but with little or no smell.” “Ignatius's bean partakes of the same qualities.”

We suspect that what was at one time generally sold to brewers for *Cocculus Indicus* was really *Nux vomica*; and that the numerous body of quacks who called themselves brewers' druggists, and who were almost annihilated by Exchequer prosecutions about ten or twelve years ago, passed the *Faba amara* and *Nux vomica* under the name of *Cocculus Indicus*, when making their defence, on the same principle as the forgers of bank-notes are accustomed to plead guilty to the lesser indictment. In the examination of Mr. Carr, the Solicitor of Excise, before the House of Commons, in the document formerly mentioned, we have the following words:

“Is it [*Cocculus Indicus*] a bulky commodity, or is it easy to be smuggled?—It is of the size of a pretty large nut; every piece of it is about the size of a nut. It bears the poisonous principle so strongly in it, that by an analysis it is very easily separated from the substance, and is produced in the form of a crystal. Now, if any druggist would take the trouble to do that, it would be possible to take as small a quantity as a thimblefull, which would poison a great deal of beer.”

Now this description agrees with the appearance of *nux vomica*, but by no means with that of *cocculus Indicus*, which is, originally, about the bulk of a black currant, but being dry when brought to this country, is of a much smaller size.

Opium is another ingredient which was formerly sold, under different disguises, by those gentlemen druggists, and which, we have reason to believe, is still in use; for we have known seizures of that article in the custody of ale-brewers, within the last two years. A compound termed *multum* was (or is) a mixture of opium and other ingredients, which sold about ten years ago, at five or six shillings a pound, when what was called an *extract of cocculus* was charged at a guinea and a-half. *Tobacco*, too, has been made use of, but how disguised we have not learned.

It will be said that every article which we have here stigmatized is medicinal, and appears in the pharmacopœias; but we also know that there is no substance, however deleterious or disgusting, which has not, at one time or other, found a place in the *Materia medica*. Besides, the parallel is imperfect. In medicine the poison is prescribed in measured doses, (less or more, according to the

prudence or the rashness of the physician,) and only in such diseases as are otherwise deemed incurable; whereas the brewer, or his drayman, administers the drugs without discrimination, ignorant and careless of the age, sex, or constitution of his patient.

In the tone of reprehension, which we have felt it our duty to assume on this subject, we trust that we shall not be accused of personality. Let it be remembered that we address ourselves to the most worthless of the trade, to such as disgrace the name of brewer, by sporting with the lives of their fellow-creatures, for the sake of gain.* If

there be any honest man so weak as to suppose that we mean to throw suspicion upon the brewery in general, we wish him to be undeceived. We are willing to believe that the number of reckless beings who use deleterious ingredients are few; but that there exist those few, is too well ascertained, from the seizures and convictions that have been so often made, and are still making, by the Excise. Our denunciations are directed solely against the guilty; and sorry should we be, if they could possibly be conceived to allude to any respectable House, or to any honourable man.

* See Coroner's Inquest in the *Times Newspaper* of the 29th of June last.

THE ART OF BREWING.

PART II.

PRACTICAL INSTRUCTIONS.

CHAPTER

Introductory.

THE *practical instructions* for brewing ale and beer, as given by different persons, are by no means uniform. The cause is obvious. The mode of manufacture, and consequently the quality, differ in every age and country; and, even in the same nation, the ale of one district has little resemblance to that of another. The London, Burton, Wiltshire, and Scotch ales are each remarkably distinguishable; and the instructions which are privately given to young brewers, take their tone from the quarter where the instructor has been bred. He who has seen only one of the modes of brewing, can have no conception of their number and variety. One shall mash three or four times, while another shall do so but once. A second shall pitch his tun at 80°, when others do so at 45°, the former cleansing in twenty-four hours, and the latter waiting three or four weeks for the finishing of the fermentation. One class of brewers attend chiefly to the attenuation, are minute in their heats of fermentation, weighing the yeast with the utmost care; while there are many gentlemen (at the same time, priding themselves on the goodness of their ale) who turn the worts into the barrels boiling hot, bung them up, and stow them for a year in their cellars, without any yeast at all. Each of these modes of brewing may be considered as producing a different species of ale; and each species has its varieties depending on natural or accidental circumstances, (such as the water, and the skill of the brewer,) which add to its preservative qualities, and give certain adventitious flavours. Porter is a peculiar species of malt liquor, and possesses a general uniformity of taste and strength: but this, too, differs in its kind; for, although confined in its manufacture almost exclusively to ten or twelve houses, an experienced palate is at no loss to distinguish that of any one house from all the others.

From what we have now stated, it is obvious that we can give no *general set of instructions* which shall apply to brewing as an abstract science. We shall, therefore, separate our directions into divisions, suitable to those species of malt liquors, with the brewing of which we are best acquainted, but without affecting, in any way, to exhaust the subject; for we have found, experimentally, during the course of twenty years, that there have occurred to us many things of which our philosophy had not dreamed.

The press has hitherto furnished very little information on the subject of brewing. Mr. Richardson's work, formerly mentioned, contains many useful *theoretical hints*; but it was not his intention to publish *practical rules*. These he reserved for private communication, by which he secured a much greater reward than usually falls to the lot of authors. His pupils were numerous; and his method of brewing, in consequence, forms one of the divisions with which the reader ought to be made acquainted. It varies extremely from that of the Scotch; and although he treats of Burton ale, his method, certainly, is not the mode by which ale could be made like the Burton of the present day. In our opinion, his directions for porter are unexceptionable, as far as they go; but that article is now very different from what it once was, and what it might be. At all events, Mr. Richardson's instructions, being very minute, will serve us for general reference, when we speak of other kinds of malt liquor; and, therefore, we shall copy them, without alteration, from a manuscript for which he was paid a hundred and fifty guineas, besides receiving a guarantee of secrecy for twenty years. Previously, however, it will be necessary to make a few remarks upon those changes which vegetables undergo, when they are understood to be submitted to what have been termed the *Saccharine* and the *Vinous fermentations*.

CHAPTER II.

Of the SACCHARINE FERMENTATION, or the Extraction of Worts from Raw Grain, and other Vegetables.

WHETHER or not the *saccharum*, or sweet, of vegetables be identically the same, wherever it is found, has not been, and perhaps cannot be, ascertained. That of the sugar-cane and the beet-root is equally crystallizable and undistinguishable; but there are many other saccharine extracts which it has hitherto been attempted in vain to crystallize. To the brewer, however, they have all one principle in common. Saccharine infusions, from whatever vegetables they may be drawn, are capable of undergoing a fermentation, during which carbonic acid is evolved; the liquid becomes of less specific gravity, acquires a vinous flavour, and gives out alcohol by distillation. These are the essential characteristics of a *sweet extract*; so much so that, instead of *saccharine*, it is more generally termed *fermentable matter*. Indeed, this is the more appropriate denomination; for, should any vegetable *sweet* be found that is incapable of this chemical change, it would necessarily require to be arranged in a different division of vegetable substances.

The saccharine matter of plants is often found ready formed in their juices, during certain periods of their growth, or in their fruits when arrived at maturity. The tasteless seed becomes sweet when it is developed into a stem; and the acid berry of the summer turns saccharine in the harvest. These are the operations of nature, which we sometimes imitate by art. In either case, the internal action, by which the sweetness is produced, has been termed *Saccharification*, and, by some, the *Saccharine fermentation*. The latter denomination has been objected to; but whether or not this change be the consequence of a real fermentation can be judged only when this term is sufficiently defined.

That portion of the flour, or farina, of the cereal grains, and of certain roots, such as potatoes, arrow-root, &c., which forms a turbid milk-like liquid, when mixed with cold water, and is deposited in an almost tasteless powder, is called *fecula*. In its pure state, it is the starch of commerce. It is this *fecula* that is converted into *sweet* in the incipient process of the vegetation of grain, whe-

ther carried on by sowing it in the earth, or by spreading it, in a moist state, on the malting-floor. Bulbous roots, too, become sweet when they begin to spring, as may be generally observed in potatoes, which, in that state, are unfit for culinary purposes.

For the oldest and best-known mode of producing the *saccharification* of barley, or other grain, we must refer our readers to the *Treatise on Malting*: there are other operations that produce a similar effect, which will come more properly under the present head. The artificial saccharification of fruits belongs to the *Treatises on the Brewing of Cyder and Perry*, and on *Wine-Making*.

The discovery of the rapid saccharification of *fecula* originated with the distillers. "It is thus," says M. Dubrunfaut, "that, in the chemical arts, practice generally precedes theoretical rules; and that the manufacturer, distant from the observations of the learned, is able to produce a certain effect, during a long course of years, before the philosopher has suspected the probability of such a production. In fact, spirituous liquors were distilled from unmalted grain and potatoes, long before the chemical doctrines admitted its possibility."

As soon as the fact attracted their attention, the continental chemists (who more than those of this country apply their science to the arts) endeavoured to elucidate the subject by their experiments. Kirchoff, of St. Petersburg, first converted pure *fecula* into a saccharine semifluid substance, by means of sulphuric acid, with long boiling; and his process, with slight improvements, is still followed by many of the Parisian distillers. This, and other means for effecting the same purpose, are detailed by the author last quoted; but the French distil their materials in a pasty rather than a fluid form, and in such a state, however saccharine it may be, it is unfitted for the brewer. The English and Scotch distillers make pure worts, and these are always capable of being converted into beer. M. Dubrunfaut's method of distilling and brewing from potatoes is worth quoting; being quite practicable, and little known in this country. We shall, however, abridge rather than copy his memoir:—

Having rasped the potatoes as fine

as possible, he put 400 kilogrammes (882 pounds) of the pulp into a brewer's mash-tun, having a double bottom; and while the workmen were stirring the mash in all directions, with oars or rakes, he mixed it with boiling water, which, the *fecula* being set at liberty, turned the whole mass into a jelly, similar to the starch of the laundress. He then added 20 kilogrammes (44 pounds) of malt, ground to a fine powder, and, at the same time, a small quantity of wheat-chaff (*courte paille de froment*) to assist the draining. The whole, being well mixed, began immediately to become fluid, and gradually sweetened, during the space of two hours, when it was drained from the mash-tun in the same manner as is done by the brewer, and carried to the fermenting-tun. A new quantity of liquor was added to the remaining pulp, as a second mash, at the heat of 50° Reaumur (145° Fahrenheit). This being stirred and afterwards drained, the pulp was squeezed in a cylindrical press, in order to get as much of the saccharine as possible, before giving the refuse to the cattle. The liquid fermented well without any deposit that could effect the distillation, and produced 54 litres (14½ wine gallons) of spirits of the specific gravity .955.

M. Dubrunfaut also applied his discovery to brewing. After having treated the *fecula* in the manner above-mentioned, he added hops, and carried the strength to the specific gravity of 1042, or about 15 pounds per barrel. The wort fermented well, and had a fine vinous smell. It was bottled a few days after, when it ripened, and resembled the beer which is made in Paris. He also fermented the wort without hops, replacing them, as is done in certain provinces, with honey, and obtained a beer which had the taste and other qualities of the famous beer of Louvain.

It will readily be supposed that other farinaceous grains and roots, that is, such as yield a portion, more or less, of starch, may also be converted into saccharine matter; and, in fact, rye, rice, maize, chesnuts, and numerous other mealy fruits, as well as roots, have been made to produce vinous liquors. In this country, however, the chief ingredient, and the cheapest for the purpose, is barley; and to this grain the brewers have, in almost every case, limited their operations. The distillers frequently make use of a mixture of

different kinds of grain, and especially oats, but the barley always predominates. We have never seen oats used in the brewery; although it is well ascertained that oatmeal formed one of the ingredients in the multifarious mixture called *mum*, which was a favourite vinous liquor among our ancestors.

The extraction of wort from raw grain was long practised by the Scotch lowland distillers; but it was not until the enormous additions to the malt duties (in 1802 and 1803) that unmalted barley was resorted to by the brewers. From that period until the year 1811, when the practice was checked by the Excise, the more scientific brewers were enabled to save two-thirds of the malt duty; and, consequently, gained an advantage over their less knowing brethren.

Although, by means of a mixture of chaff, a wort may be drawn from raw grain, with the addition of only one-twentieth part of malt, and, we believe, without any malt at all, yet such means have not hitherto been used by the brewer. During an experience of seven or eight years, we found the most convenient proportion to be that of two parts of raw grain to one of malt. The worts, in that case, run more completely from the grains after the first mash. Confined as this usage must now be to private brewings, the quantities must be small, and therefore the following directions are suited to mashes not exceeding three quarters, and at the same time (by observing the proportions), will serve equally well for brewing of half that quantity:—

The malt may be either cut or bruised, but the grain must be cut into very fine meal. The cutting must be sharp, for whatever is powdered into dust is, in a great degree, lost.

Put the quarter of malt, equally spread, on the upper bottom of the mash-tun, and over that the two quarters of cut barley. Introduce into the goods, through the descending trough of the tun formerly mentioned, three-fifths of the liquor intended for your first mash (suppose 7½ barrels) at the heat of 155°. In large mashes 150° is sufficient. This liquor rises through the perforations in the false bottom, penetrates the malt, and flows up in fissures through the grain. The goods are then well mashed with oars for half an hour at least. In large quantities it would require, perhaps, twice that time.

The remaining two-fifths (say five barrels) of the intended mash is next to be introduced in the same manner, at the heat of 200°, a few degrees more or less, according to circumstances, and the mashing is to be continued for half or three-quarters of an hour more. The tun is then to be covered and allowed to settle, which may be in an hour. At that time it may happen that a part, if not all, of the worts, will be at the top of the goods, and must be let off through the holes, in the upper part of the trunk at the side of the mash-tun, which we spoke of when describing that utensil. What drains through the false bottom will run off at the same time.

It may be noticed that the reserved portion of the first mash need not be all run on at once. The object is to keep the goods intimately mixed in liquor at an average heat of 140 to 150 degrees, (at which heat the saccharification is more readily obtained,) and for a time sufficiently long to effect that change in every portion of the dissolved fecula. During the whole of the process, the wort increases in sweetness; but neither *taste* nor *time* affords any certainty of the sweetness having reached its maximum. A quantity of unaltered starch may be held in solution, which adds its weight to the liquid, and affects the saccharometer. Although not converted into *saccharum*, it is nevertheless effectual to the distiller, because it undergoes the saccharine fermentation, along with the vinous in the working-tun. It is not, however, the same to the brewer. His endeavour is to stop the attenuation while a portion of the fermentable matter is still weighable in the worts; and it is of some consequence whether that remaining portion be saccharine, or a less altered starch.

The best criterion that has been yet found for ascertaining when the saccharification has reached its last stage, is *iodine*. This substance is a very nice test of the presence of starch, whether in a state of suspension or of solution, in liquids; and, for that purpose, it is used by the continental distillers. If we pour a few drops of the tincture of iodine into a wine glass filled with the worts of raw grain, when the mashing is just begun, the mixture will be instantly coloured of a deep blue. As the saccharification advances, the worts, with the same test, will be lighter and lighter in the tint; until, at last, the colour, remaining unchanged, will show that

the transformation of the starch into *saccharum* is completed, as far as this process is effectual for the purpose.

The goods absorb a great proportion of the liquor, so that the worts of the first mash will run very short of what is drawn from malt. The subsequent mash or mashes will present little difference of appearance from those of malted grain; and, in the proportions above stated, will, in most cases, pass freely through the goods in the ordinary way. At all events, the second and third mashes will present no difficulty.

"We should err very much," says Dr. Thomson,* "were we to suppose that the whole kernel, or starchy part of the malt is dissolved by the hot water used in brewing. At least one half of the malt still remains after the brewing is over, constituting the grains." "One hundred pounds of malt, from different kinds of grain, after being exhausted as much as usual of the soluble part of the kernel by hot water, were found to weigh as follows:—

English barley . .	50.63 lb.
Scotch barley . . .	50.78
Scotch big	52.69

"A hundred pounds of *raw grain* being converted into malt, and the soluble part of the malt extracted by hot water, the residue weighed

English barley . .	51.558 lb.
Scotch barley . . .	50.831
Scotch big	53.500

"In another set of experiments, with malt of worse qualities, a hundred pounds of malt left the following residues:

English barley . .	54.9 lb.
Scotch barley . . .	56.9
Scotch big	56.6

"It is probable," the Doctor adds, "that an additional portion of the kernel would be dissolved if the malt were ground finer than it is customary to do. The reason for grinding only coarsely is to render it less apt to *set*. But this object might be accomplished equally well by bruising the malt between rollers, which would reduce the starchy part to powder without destroying the husk."

To *bruise* the malt is certainly a preferable practice to cutting it in coarse pieces; but we have been accustomed to grind malt, as well as raw grain, with stones as small as oatmeal, without ever *setting the goods*; and this we con-

* Supplement to the Encyclopædia Britannica; article BREWING.

sider as a still better mode than cylinders, even for malt. In the case of unmalted or badly malted grain the stones are indispensable.

We are perfectly convinced that, in the above-mentioned experiments, the grist must have been either very ill prepared, or the process must have been badly conducted; for a hundred pounds of good malt ought by no means to have left above thirty pounds weight of dry grains.

Raw grain is generally supposed to yield a less proportion of extract than malt; but this, too, we are assured, must be the fault of management. We have before us the results of a number of experiments, on a very large scale, of which the following is an abstract, reduced to a thousand quarters. The grist was barley, oats and malt; the latter in a small proportion—perhaps not more than a twentieth:—

Brewed 8,000 bushels of grain, weighing	387,300 lbs.
Weight of dry extract, according to Dicas's Saccharometer, as nearly as could be ascertained	253,308 lbs.
Weight supposed remaining in the grains	133,992 lbs.

Being doubtful, however, of the accuracy of the indications of dry extract by the instrument, a known proportion of the grains was dried, until they had apparently the same dryness as the grain

had before grinding; and the weight was found equivalent to fourteen pounds per bushel. The whole of the grains were then measured, and thereby gave another and more accurate comparison. Thus,

Brewed 8,000 bushels of grain, weighing	387,300 lbs.
Sold 8,672 — of grains, ditto	121,401
The difference, being the amount of extract	265,892
Dry extract shown by the instrument	253,308
Apparent error in the instrument, being about 5 per cent.	12,584

Calculating the proportions from these two sets of experiments:—

	lbs. grain.	lbs. extract.	lbs.
By the first, 100 gave 65.41, leaving in the grains	100	65.41	34.59
By the second, 100 — 68.65	100	68.65	31.35
Average . . 100 — 67.03	100	67.03	32.97

It still appears that nearly a third of the kernel remains unextracted; more than half of which, we are convinced, is owing to ignorance of the art. One improvement, in the case now under our consideration, seems obvious: oats, barley, and malt require, each, a different heat for the proper solution of their substance. This might be applied, were each to have its separate mash-tun, but not when they are mingled into one.

Many of the remarks, which we have made in this chapter, may appear to belong to the distillery rather than to the brewery; but the two trades are intimately connected. The distiller and the vinegar-maker are necessarily brewers in the first part of their operations; and, from both, the ordinary brewer may gain instruction. All have this in common, to extract as much of the kernel of the malt, or grain, as they possibly can.

CHAPTER III.

OF THE VINOUS FERMENTATION.

IN whatever way the saccharification is produced,—whether on the malting-

floor or in the mash-tun,—the strength of the worts, that is, their power of producing an intoxicating liquid, either in the form of alcohol, or of a vinous liquor, is always accurately designated by the excess of their specific gravity beyond that of water, multiplied by their quantity. Distinct from flavour, this product may be considered as the measure of their comparative value. Thus six barrels of wort, of thirty pounds per barrel, is equivalent to four barrels at forty-five pounds: the product in each case being one hundred and eighty. It has already been shown, in Chapter V. of the first Part, that the extra-weight of a barrel of worts, beyond that of water, is only about four-tenths of the weight of saccharine matter contained in the infusion; but, the proportion being always the same, the weight thus shown by the saccharometer answers all the purposes of the brewer; and it is, therefore, of this extra-weight that the expressions “gravity” and “weight of the wort” are generally understood.

The saccharine extract (or worts) being prepared, and boiled with the hops

where that ingredient is required, is next made to undergo the *vinous fermentation*. This chemical process (which was formerly the only change in vegetable extracts that had the name of *fermentation*) operates by the destruction of the *saccharum*, both as to taste and weight; and, when carried to its utmost point, produces a liquid of less specific gravity than water, and of a taste in which the *sweetness* is little, if at all, perceptible: it is *vinous*, or that of wine.

The juices of the sugar-cane, of the grape and of many other fruits, when kept in certain temperatures, enter spontaneously into the vinous fermentation. In the brewing of malt liquors a very general practice has been, to add to the worts a quantity of the *yeast*, or froth of the previous fermentations, in order to hasten the present operation; and it was not until some experiments were made by Mr. Henry, on the effect of carbonic acid, that the chemists conceived that the fermentation of malt liquor could be produced without the assistance of yeast. Notwithstanding, the brewing of ale, without a particle of yeast, has been practised by the farmers of certain districts, in this country, from time immemorial. We have, ourselves, had the experience of worts entering into a spontaneous fermentation, without acquiring any improper flavour, or running into acidity; but they require time, and time cannot be well spared in the modern system of manufactures. What formerly required years to improve must now be brought into the market in two or three weeks. The present mode of porter-brewing is a prominent instance: the large vats, in which that article was wont to be stored for eighteen or twenty-four months, are now comparatively useless.

From the moment that the worts are mixed with the yeast in the fermenting tun, their gravity begins to decrease, and this decrease is termed their *attenuation*. A wort, for instance, of forty pounds per barrel shall, in a few hours, be reduced to ten, by the extrication of carbonic acid, the elements of which must have previously existed in a very condensed state: for, notwithstanding this immense decrease of weight, the quantity, or bulk, of the liquid undergoes no perceptible alteration.

All saccharine liquors, after they have been submitted to the vinous fermentation, are capable of producing a portion

of alcohol, by the process of distillation; and the quantity which may thus be extracted is found to be exactly proportionate to the degree of attenuation. Thus a barrel of wort that has lost forty pounds of its weight will produce twice the quantity of pure spirit which could be extracted from a barrel of wort that had lost only twenty pounds in the attenuation. This, too, is independent of the original weight of the wort; for the same extent of attenuation (suppose twenty pounds) will produce the same quantity of spirits, whether the original gravity of the worts has been thirty pounds or fifty.

Seeing that the quantity of spirit is in proportion to the attenuation, it is obviously the interest of the distiller to carry that attenuation as far as possible; and, in as far as alcoholic strength is concerned, this would also be the interest of the brewer. The latter, however, has an additional object in view, namely, *flavour*; and he finds that he cannot please the taste of his customers unless a weighable portion of the *saccharum* remains in the ale. The former, therefore, is frequently able, by strong fermentations, to reduce his worts to the weight of water, while the latter, after keeping it a twelvemonth, still expects to find from three to six pounds of gravity in his beer. It is for this reason that the brewer is so careful not to exceed in the quantity of yeast which he puts into the gyle-tun; and that, in strong ale, he wishes the tumultuary fermentation in the gyle-tun to close, while eight or ten pounds of the weight still remains unattenuated, to be afterwards slowly decomposed in the casks.

It was long a matter of contest whether alcohol exists ready formed in fermented liquors, or is produced in the process of distillation. The chemists are now generally satisfied that it is produced by the fermentation alone. They have extracted the alcohol at heats far below the boiling point of water, and by other means than by distillation; and, from those experiments, they do not hesitate to assert that alcohol, properly so called, exists in wine and beer. It is not, however, presumed that alcohol is a simple substance; and one who is not a chemist may still suspect that the atoms of which it is afterwards to be composed, although contained in the fluid, may exist in a discordant state, until united by some process that destroys their other affinities. But what-

ever may become of those theories, it is certain that these atoms, whether separately in solution or combined into alcohol, constitute a *whole* that is lighter than water; for when a wort is fermented so low as to show nothing beyond water, by the saccharometer, it still, according to the experiments of Dr. Thomson, contains about one-fifth of its original saccharum unfermented. Thus a barrel of wort of thirty pounds, when fermented to the weight of water and its alcohol distilled, will leave as much saccharine matter in the still-bottoms, as, if mixed with water to its original quantity, would make a barrel of about six pounds gravity, which might be fermented into beer. This latent weight, or unattenuated gravity, is counterbalanced by the alcohol (or its component parts), which is as much lighter than water as the saccharum is heavier. When ale or beer is attenuated in a great degree, as it usually is when exported to a warm climate, it again enters into a spontaneous fermentation, at the expense of this unattenuated, but latent, saccharum.

The acetous fermentation is the reverse of the vinous. The moment it takes place the vinous liquor becomes heavier by the absorption of oxygen; and the alcohol (or its composing principles) is destroyed, exactly in proportion to the increase of weight. If a distiller's fermenting-tun, for example, shall have been attenuated from the gravity of twenty to that of two pounds, he expects, and would procure, a quantity of spirit corresponding to eighteen pounds of attenuation; but should he, by any oversight, allow the acid fermentation to proceed unobserved, until his worts (wash) should increase in gravity two pounds, so as to show only sixteen pounds of attenuation when they had once shown eighteen, he would find that he had lost the value of two pounds, or exactly one-ninth of the quantity of alcohol which he might have had.

When a distiller's tun has ceased to attenuate, it runs rapidly into the acetous fermentation; and increases in weight at the expense of the alcohol, if (as it is said) the alcohol be really formed. According to this theory, when the attenuation is apparently complete, four fifths of the saccharine matter is converted into equal quantities of carbonic acid and spirit. With a mixture of half that proportion of alcohol, no saccharine liquor would ever become sour. Does

not this circumstance render it probable that the alcohol is not completely formed?

It is so generally allowed, that we have taken it for granted, that the acetous acid (vinegar) is formed, in vinous liquors, by the absorption of oxygen. If this be true, the contact of atmospheric air must be particularly dangerous to the ale-brewer. Various plans have been proposed to prevent its access, but none of them have been successful. In attempting to stop the *acetous*, they check the *vinous* fermentation; and it is only when the latter has completely subsided, that the vessels can be closely bunged up.

Two evils have been stated as the consequence of fermenting worts in open tuns: first, the loss of alcohol, which is supposed to escape in union with the carbonic acid; and second, the germ of acetous acid, which is believed to be communicated to the beer by the contact of the atmospheric air with the surface of the liquid. Patents have been granted, both in France and in this country, for a method of closing the tuns, so as to exclude the atmospheric air, and also to condense any alcohol that may be endeavouring to escape. The plans proposed are of very ancient date, although recently announced as a modern invention of a Mademoiselle Gervais. Our limits do not permit us to describe the particulars; but it is of the less consequence, as we should do so only to show its inutility in the brewery. To those who have seen the pamphlet which circulates the wonderful announcements of the value of the invention, the following remarks will be sufficient: those who have not seen it, may rest satisfied that its perusal would not render them wiser.

Whilst the worts are fermenting, carbonic acid is evolved, and fills a portion of the vacuity of the tun, immediately above the liquor, which excludes the common air as effectually as the closest cover. It can only be when this gas ceases to be generated, that oxygen can gain admittance; and, before that time, every skilful brewer has cleansed his beer into casks, exposing only a small bung-hole, which is also closed the moment the yeast has ceased to issue. During the whole period of the tumultuary fermentation, the pressure is *outward* not *inward*; and a lighted candle, held over the yeasty head, will shew that not a particle of oxygen can

be admitted. When this evolution of gas becomes so weak as not to form a stratum above the liquid, the introduction of air may begin, especially if the heat of the tun is high; and this, we believe, frequently happens with the distillers, (who carry the attenuation to the utmost practicable point) especially when the surface of the tun is large in proportion to its depth. A cover in this case is proper, and perhaps it would be better to have an aperture which might be contracted, so as always to preserve a certain depth of stratum of fixed air above the still fermenting liquor.

With respect to the alcohol which is said to be carried off with the carbonic acid, neither can this apply to the brewery, as generally practised. In the heat of a tun which seldom exceeds 75° , the alcohol (or whatever spirituous substance it may be) can lose little or nothing by evaporation. In the Scotch practice, the heat is almost always under 65° ; and we know not by what means the particles, that would escape at that temperature, could be condensed. If there really is a loss, it is certainly so small as to be unworthy of attention.

CHAPTER IV.

Practical Instructions by Mr. Richardson.

ART. I.—FOR MILD ALE IN GENERAL.

1.—Heat of the Liquor.

THIS being an ale which requires early purity, the first heat of the liquor must therefore scarcely ever be under, and is not seldom above, 180° , to which 5° are to be added for the second mash, and 5° more for the third, where three mashings are made for strong ale; but where there are two only, the addition may be 10° ; that is, 180° and 190° . If, however, you find by experience that a lower heat of the liquor will produce purity, this will be a preferable practice, as producing a more mucilaginous wort, and it is better calculated for making small beer after it. It is therefore advisable that you begin with the heat of the liquor just mentioned, and then try 175° for the first mash, varying 5° at a time in different brewings, for the sake of practice and experience. Sometimes, indeed, when I take my first heat at 180° , or higher, I only increase 5° for my second, though I have but two mashings for strong ale, in order to avoid

that thinness on the palate, which too high a heat is sometimes apt to produce.

§ 2.—Time of Infusion.

If there be only one mash for strong ale, as is sometimes the case for ale of great strength, the time of infusion should be four hours. If there be two mashings, allow three hours for the first, and two or two and a half hours for the second; and if three mashings, allow two and a half or three hours for the first, two for the second, and one and a half or two hours for the third; it being intended to allow as much time as is consistent with the proper forming of the extract, and the necessary expedition of the process.

§ 3.—Quantity of Hops.

To ale made from worts whose average specific gravity is about thirty pounds (which answers to about two barrels from a quarter of malt), not less than two pounds of hops should be used in winter, and more as the season advances, even to four pounds in a great heat of the atmosphere; or it is perhaps more rational to apportion the hops to the malt used, in which case eight pounds per quarter are allowed, for the more certain preservation of the ale. This being adapted for the climate of England, a greater portion ought to be allowed where the heat of the air is greater.

§ 4.—Time of Boiling.

This in general, should be only till the wort breaks pure, in order to extract only the finer parts of the hops; but in great heats of the air, a longer time in boiling, as well as a greater portion of hops, is necessary for the preservation of the ale. For this purpose, also, (having in view a finer flavour in the ale,) it is advisable to boil the wort for an hour or more, before the hops are added, which renders it more preservable, at the same time that it avoids the rank extract of the hops. If, however, those produced in Worcestershire be used, the mildness of their flavour renders this precaution unnecessary.

What is meant here by *breaking pure*, is that state of the wort when the hops subside to the bottom, and the mucilaginous parts of the malt are coagulated into large lumps, and float up and down in it, very rapidly, leaving the interstices of the wort perfectly pure. This generally happens (when the wort is boiled

briskly, as it ought always to be) in about twenty or twenty-five minutes in the first wort, but is somewhat longer in the others. The mode of observing it is, to take a little wort in a bowl or dish, after having boiled about a quarter of an hour, and let it stand steady to observe the effect; and, by doing so every five minutes after, for two or three times, you will note the difference, and soon become a competent judge. Without making this observation, you cannot err much in boiling the first wort about three-quarters of an hour, and an hour or an hour and a half the second; or if you boil altogether, the whole time may be allowed. This, however, respects the extract of the hops rather than the effect it is to have on the wort; and is intended only for the winter season, and when the ale is for present use.

5.—*Method of Fermentation.*

As in this part of the process the greatest effects are produced by the heat of the fermentation, so the greatest attention to its progress is necessary. The first heat (that is, when all the wort is first in the gyle tun) is to be considered of no other consequence than as conducing to the *lust* or highest heat to which the fermentation will arrive; and this is found to have a very important influence on the flavour and other qualities of the ale. At 75° the first flavour of mild ale commences; for under that it is more properly the flavour of ale intended to be improved by long keeping. At 80° the flavour of ale is more perfect; at 85° it approaches the *high flavour*; at 90° it may be termed *high*, but is sometimes carried to 100° and upwards; the flavour increasing as the heat of the fermentation rises. It must still be remembered that I refer to the highest heat; and therefore at whatever degree you would have the fermentation finish, you must begin it at such a heat as experience has taught you will rise at last to the desired heat, but no higher. For instance, a wort of thirty pounds per barrel ought to increase about 15°, so that in order to arrive at 80°, you must begin at 65°; but as it is impossible to say how your yeast will ferment (upon the quality of which the success of this operation entirely depends), it were safer in a small gyle, and in a low heat of the atmosphere, to begin at first between 65° and 70°; and if you find it increase 15° or more, you are to lower the heat of your next gyle accordingly;

that is, so as to bring your highest heat of fermentation between 75° and 80°, or not much to exceed the latter; for, though a high heat produces the most agreeable flavour, the ale will not ultimately be so lively, nor will it be so soon fine, as from a contrary practice. It may not, however, be amiss to remark, that Forlow's celebrated Cambridge ale was begun at the heat of 90°, and has been sometimes carried as high as near 110°, producing that peculiarity of flavour which rendered his and the ale at one of the colleges by the same man, so famous, that some of it has been drunk at the king's table.

The quantity of good solid yeast to be used, should be proportioned to the specific gravity of the worts, the prevailing heat of the weather, and the heat of fermentation. To a wort of thirty pounds per barrel, if the heat of the air be low, and the first heat of fermentation. 65°, or a little more, two pounds per barrel, or more, may be used. If the first heat be 70°, or not much under, 1½ or 1¾ lbs. may be sufficient. This, when the first heat is about 70°, may be all used at first; when it is lower, two-thirds may be used at first, and the remainder the next morning. In either case the quantity first used should be put into the gyle-tun, and as much wort let down to it as will cover the bottom, one and a half or two inches. The heat of this wort should not be less than 85° or 90°, in which state, being well mixed with the yeast, it puts it into immediate action, and prepares it for the reception of the rest of the wort at the required heat. When an addition of yeast is made, the whole should be well roused, to mix them the more readily.

These previous steps being taken, there is nothing uncertain but the strength and consequent operation of the yeast; and if the heat of the fermentation fall considerably short of the increase before-mentioned, the whole fermentation will be imperfect, the ale will have a heavy mixed flavour of sweet and bitter, and the fault is to be attributed to nothing but want of strength in the yeast. This can only be remedied by a fresh supply from some other brewer; and you must not be disheartened if the first or second change should not succeed; for there must be a new supply procured till some be found which will answer the desired end.

Even when a perfect fermentation is procured, the strength of the yeast will

in time degenerate, and render another change necessary; and particularly so when the fermentation is carried to its utmost extent.

It is also to be remembered that I do not recommend rousing the worts in the gyle-tun, except as before-mentioned, because it communicates a rank flavour of yeast to the ale, though it perhaps adds to its strength: this rule, however, can only hold good when the yeast is of sufficient strength; for, when it is weak, or suspected of being so, it will be necessary not only to increase the yeast considerably, by additions at every three or four hours during the day after brewing, but to rouse, at every addition, and even to continue these rousings till cleansing, in order to carry off the saccharine of the malt, and produce, as much as possible, that uniformity of flavour which good yeast would have effected in the first instance.

§ 6.—*Rules for Cleansing.*

It is my practice to look every two hours into the gyle-tun, during the fermentation, whence I observe its progress very accurately. My principal attention is directed to the heat of the fermentation, which generally increases very slowly at first, but when the fermentation is in full force, its general increase is half a degree per hour, which progress declines in proportion as the fermentation advances towards a conclusion, till at length it stands still, and sometimes decreases before the vinous fermentation is entirely complete, especially where the volume of wort is small. This, then, is the grand rule for cleansing: whilst the heat is increasing, you may rest assured that the vinous fermentation is not finished; but so soon as it is at its height, you are to turn your attention to the smell of the ale. Whence you will observe, that in the middle of the fermentation, the fixed air strikes into the head so powerfully, on smelling with the nose lower than the upper edge of the gyle-tun, that it would, perhaps, be death to inhale it a second time, without intermission; but this force so much abates towards the conclusion of the fermentation, that, at the proper period for cleansing, it no longer stings the nostrils, nor strikes violently into the head, but just feels warm, and being drawn into the lungs, only occasions strong efforts to discharge the gas exactly similar to the effect of a sudden exertion in running up a hill, vulgarly termed

being *out of breath*. The ale will then have lost its saccharine if the fermentation has been perfect, and will have acquired an uniform vinosity both in its smell and taste. The head will also then have a regular compact appearance of yeast, provided it be so low a heat of fermentation as 75° or a little more, but in proportion as the heat is carried further, the head becomes less; so that a fermentation of 90° or more will only exhibit blistery bubbles, and discharge no yeast till the ale be cleansed into casks, which, in that case, should not be larger than barrels, because it requires the heat to be lessened as expeditiously as may be, to facilitate the discharge of the yeast, and larger casks would be apt to retain it too long.

It is an advisable practice, when the fermentation is carried to its utmost period, to use about seven pounds of flour from either wheat or beans, to a gyle of 25 to 30 barrels, at the time of cleansing, in order to accelerate the discharge of the yeast by the introduction of an extra portion of gas into the ale for that purpose. This should be whisked up in a pail, with some of the ale, till all the lumps are broken, when it may be enlarged to any specific quantity, and then having a portion poured into each cask, agreeably to its size, the ale is to be cleansed upon it.

Though the above rules for cleansing are entirely consistent with my system, I nevertheless have found it convenient to deviate from them, by cleansing at an earlier period, even while the heat of fermentation is yet increasing, and the fixed air is somewhat strong, in order to obtain a better produce of yeast, and thence to have less sediment in the casks, which sometimes subsides with difficulty after removal. By early cleansing, too, the yeast is preserved longer in a state proper for a perfect fermentation, than by a contrary practice. At any rate, however, there must be no saccharine taste perceptible at the time of deciding upon cleansing. When the cleansing is finished, the casks should be filled quite full, and be filled up out of the stillions every two or three hours during the first day, and three or four times the next. When the ale has nearly done its fermentation, if that from the stillions does not run clear, a cask should be tapped, to fill up with, and that which is thick should be returned into the next gyle just before cleansing.

If the ale be racked off from its lees,

about three or four days from cleansing, and you add to every barrel three pints or two quarts of hops, after having boiled in the first wort, and (when the heat of the air is low) whilst they are warm, it will contribute much to the liveliness and purity of the ale, and render it much less liable to disorder, in removing from cellar to cellar; but it is to be observed, that the hops thus added give some rankness to the flavour, and racking is not favourable to the preservation of the ale. In this practice the casks should be filled quite full, and bunged down close, venting only if the cask be in danger. But if the ale be not racked, the casks should not be bunged down so long as the head of the ale can be kept up by repeated fillings; for otherwise there would be a circle of yeast formed round the inside of the bung-hole, which would be in part washed off amongst the ale on removal, and tend to make it foul.

CHAPTER V.

Richardson's Instructions continued.

ART. II.—FOR OLD ALE, or such as is to be long kept.

§ 1.—Heat of the Liquor.

As purity is not immediately required in this sort of ale, the first mashing heat should be as low as practicable; that is, so as just to avoid acidity in the wort, which is apt to be produced by a very low heat of the liquor. Hence 160° or 165° may be the first heat, and from 10° to 15° may be added for the second, if there be but two mashes, and 10° each if there be three. Thus if the first heat be 160° , and you find no tendency to acidity in the last running of the worts, then these rules may be observed; but if there should be a little acidity discernible, it were advisable to make the increase 4° or 5° more for the subsequent mashes, and on brewing another gyle of the same sort, from the same malt, it were best to begin at 165° , and then observe these rules for the next mashings.

§ 2.—Time of Infusion.

If the heat of the liquor be very low, the time of infusion should be somewhat less than that allowed for mild ale. Therefore, two, or two and a half hours may be allowed for the first mash, and one hour for each of the rest.

§ 3.—Quantity of Hops, and time of boiling.

The general rule for hops is one pound per bushel of malt; but if it be intended that the ale should retain its mildness to a very distant period (which by the bye is to answer a very useless purpose), a larger portion of hops must be used, agreeably to the intention of the brewer.

The boiling is regulated by time, as the nicety of flavour is not such a requisite in this as in mild ale. In two worts the boiling may be from an hour to an hour and a half for the first, and two or two and a half hours for the second; in three worts, the first may boil one hour, the second an hour and a half, and the last two or two and a half hours.

§ 4.—Quantity of Yeast, and mode of Fermentation.

If the first heat of fermentation be not below 60° , and the gravity not much more than thirty pounds, provided the air be temperate, the quantity of yeast must be from two to two and a half pounds per barrel, applied in the manner as directed for mild ale. If the heat be lower, the specific gravity more, or the heat of the atmosphere less, the quantity of yeast must be increased in proportion; in doing of which, no great inconvenience can arise from applying a few pounds too much, but it may occasion an imperfect fermentation if there be a few pounds too little.

The heat of the fermentation should not exceed 75° at the highest, but rest between that and 70° , though the nearer 75° the better will be the flavour of the ale at an early period; and as a low heat of mashing is conducive to a great increase in the heat of fermentation, it will thence be evident that the fermentation for ale, whose average gravity is thirty pounds, must begin at or below 60° , and the precautions before recommended respecting the yeast, must be particularly attended to. The mode of conducting the fermentation, and the criterion for cleansing, being the same with those directed for mild ale, a repetition here would be superfluous.

I, however, recommend a more strict adherence to the rules for cleansing, before inculcated in this process, than in that for mild ale, because the first heat being lower, a greater time is necessary to bring the fermentation to perfection, and secure the future good flavour of

the ale. It may be here observed that this sort will generally require finings.

ART. III.—FOR SMALL BEER.

If this be made alone, the same rule is to be observed in the heat of the mashing as that recommended for keeping ale; but the time of infusion is somewhat less. If made after strong ale, as there cannot with propriety be more than one mash, the heat may be 160° or under.

It is generally boiled at once about an hour or an hour and a half, according to the season or the time required to keep it; and it may be observed here, that long boiling prevents its fermenting so freely as it otherwise would do.

The quantity of hops must also depend entirely on the taste of the consumer, and the time required to keep it. When made after mild strong ale, there is generally a sufficient quantity of hops to prevent the necessity of a fresh application, and after keeping ale, the quantity is often so large as to render it necessary to leave some out of it.

The first heat of fermentation may be from 60° to 65° , and, as there is rarely any material increase, it may be cleansed at the end of 12 to 14 hours, when the fermentation is fairly begun; for if it was carried to its utmost period, the beer would be thinner upon the palate, and appear not so strong as it would by the mode of fermentation here recommended.

About a pound of yeast per barrel will be sufficient.

ART. IV.—FOR EARLY HARD ALE, or a mode of producing premature acidity in Ale.

This is nothing more than the artificial introduction of an acid flavour into new ale, to suit particular palates, which flavour must otherwise have been the effect of age. Add to a barrel from one to two gallons of common vinegar, or rather of ale which has acquired a great degree of acid flavour, according to the taste of the consumer whose palate is to be accommodated.

This should be done at such a time as the ale to be changed has discharged the greatest part of the yeast, which may be about twenty-four hours after cleansing, where the heat of fermentation has been low, and from twenty-four to thirty-six hours where it has been high. Some-

times hops are used as in racking of ale. In either case the cask must be filled *nearly full*, and stopped down close, that a violent internal vinous fermentation may ensue, otherwise the union will not be perfect, but the distinct flavours of both will be discernible. If the commotion within seems to endanger the cask by the swelling out of the head, &c., a little of the ale may be drawn off occasionally, but it is to have no other vent.

This fermentation will sometimes continue for three or four weeks, and when it is finished, so that the ale will become pure with finings (which it will require), it will be fit for use.

ART. V.—OF RACKING KEEPING ALE.

Whether the ale be racked from vats or from one cask to another, it has a tendency to grow flat. This may be remedied by adding about two quarts of hops to a barrel, as mentioned in racking mild ale; but a better mode is by an addition of a sixth to a fourth part of new ale taken from the gyle-tun, in a state proper for cleansing. In either case the cask is to be filled full, and stopped down close, with the same precaution as recommended under the article of *Early hard ale*. I have also seen about a quart of good wort (made perfectly pure by filtrating through a flannel bag) added to a barrel of mild ale, which was flat, but also pure, and, in a very short time, it produced all the liveliness of bottled ale, without having in the least injured its purity; but having had little occasion to pursue the practice, I give it here as a hint well deserving your attention, should you ever have occasion to adopt it.

ART. VI.—FOR BURTON ALE.

This is made from the palest malt and hops; for, if it be not pale as a straw it will not pass with the connoisseurs in that article; and the gravity being so very high as thirty-six to forty pounds a barrel, makes it a matter of great nicety to get malt sufficiently pale.

If the malt be not very good, only one mash must be made for this liquor; but if it be good, two mashes may take place, adverting still to the great specific gravity which ought to be produced.

The heat of the liquor should be 185° , or 190° , adding 5° for the second,

if a second mash be made; and the time of infusion may be the same as that mentioned under the article *Mild Ale in general*.

If only one wort be made, it may be boiled an hour and a quarter; if two, they may be boiled three-quarters of an hour the first, and an hour, or an hour and a quarter the second; remembering that long boiling is prejudicial to the colour.

The quantity of hops must be three-quarters of a pound per bushel of malt, or more, according to circumstances; but the more that are used, though an advantage as a preservative, the higher will be the colour of the ale.

The heat of fermentation should not much exceed 75° , and as the first heat would thence probably be about 55° , the quantity of yeast, both on account of this circumstance, and the great weight of the wort, should not be less than three pounds per barrel, used as is before recommended; and the rule for cleansing is the same as that before inculcated.

It is to be racked into clean casks (without hops) when nearly pure, and the sizes of them are from 32 to 42 or 43 gallons (called *half hogsheads*), and from 70 to 80 gallons (called *hogsheads*), which are generally hooped with an equal number of iron and wooden hoops; the latter are white, flat, or broad bark hoops; a bar is put across each head, and the brewer's initials or name, with B or BURTON at length, are branded in front in letters of about an inch and a quarter high; and the number of gallons which the cask holds is cut with a scribe-iron, just above the cork-hole.

The bung-hole is not above an inch and a quarter diameter, which is stopped with a wooden shive or bung, and a piece of triangular tin-plate is afterwards nailed over it.

CHAPTER VI.

Richardson's Instructions continued.

ART. VII.—FOR PORTER.

§ 1.—Heat of the Liquor.

The heat of the liquor may begin from 156° to 165° , it being intended to go as low as the avoiding acidity in the wort will admit of; and, as a large portion of the malt in this is brown, the heat of the liquor may thence be, with safety, somewhat lower than in the process of keeping ale.

The subsequent heats of the mashes

are to be increased from 5° to 10° each, according to circumstances, though the former is generally sufficient. If, however, the ranker earthy parts of the malt be desired, in order to heighten the flavour; or if the taste of the preceding wort has been somewhat inclined to acidity, then 15° may be added, supposing a very low beginning.

§ 2.—Time of Infusion.

This, on account of the number of mashes, need not be more than two hours at the first, and one hour for each of the rest; but as the time of boiling allows more time between the two last mashes than usual, the time of infusion may be proportionately long, without wasting any.

§ 3.—Quantity of Hops, and Time of Boiling.

It is not, perhaps, so much for the purpose of preservation as for that of flavour, that the general practice is to use not less than four, and sometimes four and a half to five pounds per barrel for *keeping*; though what is termed *mild* or *mixing* porter, has not more than three to three and a half pounds; but since hops have been so very dear, these proportions have been so considerably lessened, that I do not even now use more than three and a half pounds for *keeping*.

The hops required here are to be *strong*, without regard to colour; and for the purposes of extracting all that strength, and communicating all its rankness, the whole of the worts are generally boiled from eight to nine hours in the aggregate; which may be apportioned, in three worts, to one and a half, two and a half, and four or five hours. If there are four worts, it may be one, one and a half, two and a half, and three or four hours.

§ 4.—Mode of Fermentation.

The heat of fermentation to be so low as not to exceed 70° when at the highest, so that in general it may begin about 60° ; and should it be inclined to go further than 70° , provided the saccharine of the malt be not perfectly gone off, the event of a degree or two more may be waited for, in case the heat of the fermentation does not increase more than half a degree in the hour at that time, when it is to be cleansed at all events; otherwise, it might run up so high as to induce the flavour of keeping ale instead of that fulness which porter

ought to have. If, when the heat of fermentation is at 70° , it is increasing more than is above mentioned, I recommend that the porter be cleansed, lest the major part of the yeast subside to the bottom of the casks instead of being thrown ont, and thence render the porter foul, and hereafter stubborn, if not cloudy. At this period of the fermentation, though every other rule relative to cleansing be dispensed with, yet care should be taken that the sweetness of the malt be gone off; and to facilitate that end, a greater portion of yeast is to be used than is allowable in any other beer of the same strength. The quantity required is from three to four pounds per barrel, used in the usual proportions, and rousing the wort every two hours in the day time, and even during cleansing, if practicable, in order to give every degree of rankness obtainable from the materials.

In order to heighten the flavour, about a quarter to half an ounce of socotrine aloes per barrel may be boiled in the second wort; and, for the purpose of giving a retentive head, as much salt of steel as will lie on a half-crown piece is to be added to a barrel, with the finings. These effects may, indeed, be increased to any desired degree, by increasing the quantity; but it is to be remembered that aloes is a powerful purgative, and much more than half an ounce per barrel might discover itself, nor is the salt of steel sufficiently wholesome to warrant the use of any large quantity. The former of these I now entirely omit, and in its place use quassia, in the proportion of a pound to twenty barrels of porter, or a little less; and, as a saving, copperas may be substituted in the place of the latter.

The malt used is generally brown, amber, and pale, in equal quantities; but it is necessary, in that case, to have the former browner than is always to be met with; and the second of a deeper tinge; it may be as well to use brown and pale in equal parts, or in such other proportions as the colour of the former shall indicate to be necessary even to two-thirds or more: and, as it is essential, both for colour and flavour, to have a sufficient portion of brown, an error on that side would be much more safe than on the other; for the want of colour, and consequently of flavour, is often a great obstacle to the reception of porter, in a country where its production is novel, by rendering it more like

ale than is admissible in such a situation; where it is generally expected to find in it qualities which, in the known produce of London, would not, perhaps, be demanded.

The malt, both brown and amber, are dried with wood, either billets or very stout faggots; but this being for the sake of flavour only, where there is a deficiency of this fuel, the foundation or body of the heat may be produced and continued with cinders, adding some wood.

When the porter is worked off, it should be started into vats, of any convenient size, from 50 to 500 barrels, and racked thence for sending out; in doing which it is preferable to rack the whole off at once, that there may be no ullage, which is apt to become vapid and often sour. It should not be racked till on the fret.

§ 5.—*Of the average Specific Gravity requisite for different Ales and Porter.*

For Burton ale, as is before intimated, the first sort is from forty to forty-two, or forty-three; the second from thirty-five to forty; and a third sort, made after the former, is from twenty-eight to thirty-two, or thirty-three pounds per barrel.

This latter is the usual gravity for common mild strong ale, of the first quality; but the more prevailing weight for common ale is from twenty-five to twenty-seven; and even since malt became so valuable, from twenty-two to twenty-four is deemed sufficient; whilst in certain situations twenty to twenty-one is thought to be as much as the price merits.

For keeping ale which is similar to the above, only in being longer kept before used, the same gravities are requisite.

For porter, about eighteen is sufficient for the common sort, twenty for what is sometimes termed *double*; twenty-two to twenty-three for the first kind of brown stout, and twenty-five to twenty-six pounds for the very best brown stout.

The weight for common small beer is about six or seven; and what is deemed good table beer, is from twelve to fourteen pounds.

ART. VIII.—*OF RETURNS for saving Malt.*

After the usual process of brewing is finished, you are to cause one or two

mashes to be made, according to circumstances; viz. if small beer has been made, only one mash is to take place; but where that has not been the case, there may be two; for the more the malt is exhausted, the greater is the saving, and the greater the number of mashes, the more fermentable matter is extracted.

If, therefore, no small beer is intended to be made, you are to mash for a return in the same manner as if small beer was to be made, only using as much more liquor as is convenient; taking the heat at 160° or 165° , letting it infuse an hour or more, and then pumping it up into the copper, and putting the hops into it, but it is only to be just made to boil when it is to be turned into the cooler in the usual way. During this another mash for a second return is to be made, taking the heat at 5° lower than the first, which return being pumped up into the copper, and the hops added to it, it may remain in the copper all night at a heat nearly boiling, and then be turned into the cooler as the former.

These two returns are to remain in the coolers until the evening before the next brewing, when they are to be let down into the under back and pumped into the copper, to serve for the purpose of mashing, in the place of so much liquor; and if there be more than sufficient for the first mash, the remainder may have as much liquor added to it as will serve for the second. But as the return contains a certain portion of fermentable matter, that portion is to be previously ascertained, and either an additional quantity of liquor is to be used in the brewing, or so much malt be left out of the grist as the amount of that fermentable matter may be.

To ascertain this, it may be premised that the gravity of the wort intended for small beer is generally from three to five, more or less, and that the wort drawn after this (if the quantity be the same as that of the wort for small beer) will have half, or rather more than half the weight of that; so that supposing the gravity of the wort for small beer to have been 3.5, the wort intended for a return would probably be 2.0; in which case, if the volume of the wort amount to twenty barrels, the sum would be forty pounds, or upwards of half a quarter of malt. On the contrary, if no small beer be made, the

mash which would have been made for that wort must now be made for a first return, to which another mash, as above mentioned, would produce a second, whence the saving would be nearly threefold of the one effected after making small beer; for, supposing twenty barrels of the first return at 3.5, the aggregate would be seventy pounds, to which the second return (as above estimated) being added, the total would be one hundred and ten pounds, or nearly one quarter and a half of malt, valued at seventy-five pounds per quarter.

But as this estimate only relates to the return in the under back, it is to be remembered that an addition would be made to the amount, as exhibited in that state, by that portion of the preceding worts which is imbibed by the hops, and which will be extracted and replaced by the return into which those hops are put; but this addition can only be ascertained by actual experiment. Whence *the net aggregate saving is to be estimated from the gravity of the return taken when cold in the cooler*, as including the above-mentioned addition from the hops, and not from the return in the under back, the aggregate of which will be found to fall considerably short of that of the return in the coolers, particularly where many hops are used.

There is also some advantage derived from the hops having their virtue further extracted by this process; but as an estimate of the *quantum* cannot easily be made, it is not taken into the account of the saving effected hereby.

The intervention of a day or two between the brewings is no bar to the use of a return. Its very humble specific gravity is a security against fermentation. In summer we sometimes have it lie a week; and, in very warm weather, it will mould a little at the top without injuring its taste. I do not, however, use it for strong ale in such cases, but mash with it for another return, that the flavour and purity of the former may not be affected by it; but for porter I never hesitate to use it at first, and we generally contrive to brew a gyle of the latter after one of the former, with that intention.

ART. IX.—OF THE BREWING BOOK.

The following is the plan of my brewing book:—

BREWING-												
1	2	3	4	5	6	7	8	9	10	11	12	
Malt.	Hops.	H. Liq.	Liq.	Wts.	Grav.	Sum.	Boil	Worts.	Grav.	Sum		
1800												
12.8	48	170	24	14	32.8	452	1	10	38.0	380		
X & T	(76)	175	14	14	18.0	248	1½	11½	23.0	264		
No. 16		180	14	14	9.5	131	2½	9½	14.0	133		
			52	42		831		31	25	777		
		165	15	15	5.4	80	1	12	7.5	90		
						911				867		
12.11	108	150	26	16	28.2	444	1	12	32.5	390		
P	(75)	155	15	15	15.6	231	1½	12½	18.0	225		
5½-0.6½		160	15	15	9.5	140	2½	13½	12.0	162		
No. 17		165	16	16	5.4	85	3	12	8.0	96		
			72	62		900		50		873		
	24	156	Carried over.									

BOOK.

13	14	15	16	17	18	19	20	Remarks.
Yeast.	Heat of Fer.	Hours.	X.	P.	T.	Fermentation.		
40	74½	11½				Time. Heat		
						8 E. 7 74½		
						9 M. 8 79		
						— 10 80		1½ O.P.
						— 12 80½		
						E. 3 81½		
12	66	1	31		12	— 5 82½		
			(25)		(7.5)	10 M. 8 86		
140	65	7				12 M. 4 66		
						— 9 66½		
						— E. 1 66½		
						— 5 67½		2 Q.
				50		13 M. 9 72		
				(17.5)		— 11 72½		
						E. 1 73		
			31	50	12			

EXPLANATION.

Suppose the Book lying open, as in the two pages* before us, both of which are to be taken across as continued lines of the same Table:—

Column 1, contains the date and quality of each brewing as successively numbered No. 1, No. 2, &c., from the beginning of the year, which is here counted from the 1st of October. The two examples are reductions of two of my own brewings for twelve quarters. Herein 12.8 means December 8th; X and T are strong beer and small; P is porter; and the figures $5\frac{1}{2}$.0.6 $\frac{1}{2}$ denote $5\frac{1}{2}$ quarters of brown malt, no amber, and $6\frac{1}{2}$ quarters of pale. Column 2 shows the quarters of malt used, and col. 3 the pounds of hops, both of which are summed up at the bottom of every page, so as to show the quantity used at the close of the year. Col. 4 is the heats of liquor for each mash; and col. 5 is the barrels of liquor. Col. 6 is the quantity of worts drawn from each mash; col. 7 is the gravity per barrel taken in the underback; and col. 8 is the whole weight of fermentable matter, deducting one and a half per cent. for heat. Col. 9 gives the hours each wort is boiled. Col. 10 gives the worts in the coolers; col. 11 their gravity; and col. 12 the sum of the gravities multiplied by the quantities. Col. 13 shows the pounds of yeast. The double column 14 gives the first heat of fermentation, and its increase in the gyle-tun; and col. 15 shows the hours which it remains in the tun before cleansing. Columns 16, 17, and 18 show the quantities of strong ale, porter, and table beer brewed; and these, like those of the malt and hops, are summed up on each page, and carried forward to the succeeding one.

The next column contains minutes of the progress of the *fermentation*. Thus, in the first example, 8 Ev. 7—74 $\frac{1}{2}$ shows that the yeast was put to the worts, at 74 $\frac{1}{2}$ degrees of heat, on the 8th of December, at 7 o'clock in the evening. Its progress through the next day is marked in the same manner; and on the 10th, at 8 in the morning, the ale appears to have been cleansed; having acquired an increase of 11 $\frac{1}{2}$ ° of heat in the course of thirty-six hours.

The last column or space is left for remarks. Those here inserted signify

1 $\frac{1}{2}$ pound of orange peas, and 2 pounds of quassia.

The figures in column second, marked with *red ink*, [here within parentheses] (76) and (75) is the produce per quarter, as shown by the saccharometer. The same sort of figures in columns 16, 17, and 18 give the weight per barrel of the different beers.

With respect to the high fermentation mentioned when speaking of Cambridge ale, Mr. Richardson has given no examples; and our practice, in this kind, has been so limited, that we can only exhibit a single brewing, on the results of which we can depend. This was a brewing of eight quarters of malt, with forty pounds of hops. It immediately followed one from which there was a Return of eighteen barrels, of four pounds specific gravity, which was made use of for the first mash. It was in the month of February, and the weather was uncommonly mild.

	Barrels.	lbs.	
1st Mash 18	gave 11	at 34	= 374
2d Mash 10	10	- 20	= 200
3d Mash 10	10	- 10.5	= 105
		31	679
Return 16	16	- 3.	= 48

The three worts when boiled produced 22 $\frac{1}{2}$ barrels at 29 lbs. per barrel; and this with the Return (which infused with the hops showed 15 barrels at 4 lbs. per barrel) gave a produce; on the whole, equal to eighty pounds per quarter.

These 22 $\frac{1}{2}$ barrels were pitched at 78° with four gallons of yeast. In thirty-six hours the heat rose to 94°, when it was cleansed at 14 lb. gravity. In about a fortnight it was pure, and turned out to be excellent ale.

CHAPTER VII.

OF THE LONDON BREWERY.

WHILE the character of the London ale is so low as to be unknown beyond the precincts of the metropolis, that of the porter remains unrivalled. Tastes are acquired by habit, from which cause, when in continued action, we get inured to the strangest beverage. The immense capitals and influence of the ten or twelve principal houses defy all competition, and whatever malt liquor they may agree to designate by the name of porter must, eventually, pass current with the multitude. This is no random assertion; for it is well known that the liquor now retailed under that denomi-

* On two pages in the Manuscript, but here printed on one.—EDIT.

nation has little or no resemblance to what was so called thirty years ago. Whether it is better or worse, or whether there can now be any criterion of comparison, in that respect, is no part of the question.

"Before the year 1730, the malt liquors in general use in London were ale, beer, and twopenny, and it was customary for the drinkers of malt liquor to call for a pint, or tankard, of half-and-half, that is, a half of ale and half of beer, a half of ale, and half of twopenny, or half of beer and half of twopenny. In course of time it also became the practice to call for a pint, or tankard, of *three threads*, meaning a third of ale, of beer, and of twopenny; and thus the publican had the trouble to go to three casks, and turn three cocks, for a pint of liquor. To avoid this inconvenience and waste, a brewer of the name of Harwood conceived the idea of making a liquor which should partake of the same united flavours of ale, beer, and twopenny. He did so, and succeeded, calling it *entire*, or *entire-butt*; and, as it was a very hearty and nourishing liquor, it was very suitable for *porters* and other working people: hence it obtained the name of *PORTER*."

It is not to be recorded in honour of the chemical arts, but it is nevertheless true, that many of the now indispensable ingredients and manipulations originated in the wish to deceive. It was early known that what was then termed the *fiery* nature of newly distilled spirits became softened by long keeping, but it was found, at the same time, that when, as was usually the case, they were kept in oak casks, the liquor acquired a brown tinge, more or less deep, according to the time of maceration; and hence, with the unobservant purchaser, colour was taken for the criterion of age. This error, however, is now exploded; and every one knows that rum and brandy owe their beauty to artificial infusions. In a similar manner, all other things alike, ale and beer assume a lighter or a deeper dye in proportion to the quantity of malt-extract which they contain; because malt, however carefully dried, always acquires some degree of colour from the kiln. Colour, therefore, with the many, was long considered as indicative of strength.

The manufacture of fine ales (before they were contaminated with hops) was intended to imitate the white wines of

the continent; and, consequently, in those times, the paler malt the more valuable it was, in that respect, to the ale-brewer. Nevertheless, when the quantity of malt was great, the worts were always partially coloured; and the produce being termed "*strong or mightie ale*," induced the public brewer to make two beverages from the same malt of equal strength but of different colours, until at last *pale*ness was gradually disregarded. In the case of beer, which contained numerous ingredients, the quality of the malt was less attended to. The harvesting of barley was then more troublesome than now, and much of it was moulded and stained. To hide these defects in the malting, it was coloured on the kiln, and hence the early manufacture of brown malts, which were sold only to make beer. Brown malt always smells of the fire; and this empyreumatic flavour, becoming in request, was heightened by drying with wood faggots, chiefly beech, because that sort of wood was formerly of little value. Thus did beer acquire a deep colour; and when hops were introduced, and subsequently enforced by legal enactments, the bitter principle being all that was sought for, the brownness of colour and the coarseness of the flavour formed no objection to their use.

When the saccharometer was applied to the brewery, it was discovered that the colouring matter of brown and amber malts was formed at the expense of the *saccharum*; and this added to the knowledge that these sorts of malt were made from barley which was unfitted for the paler kinds, rendered it desirable to find substitutes for flavour and colour from other substances. The sale of colouring was at first private, but being authorized to be made from sugar by the 51 Geo. III., it became a trade; and, under cover of that article, other ingredients were sometimes introduced which were neither legal nor useful.

In 1816, all ingredients, other than malt and hops, were forbidden, and consequently the manufacture of sugar-colouring was discontinued; but in a short time after, a patent was taken out for the making of colouring by the roasting of malt: and this colour, being legal, is made use of by those brewers who prefer it to the old mixture of brown and amber. When this roasted malt is put into the mash-tun, all the rest of the malt is pale; and the proportion of black to pale is about one to forty or

fifty, according to the degree of colour required."

Whether it is produced from brown, amber or black malt, from burnt sugar or burnt molasses, the colouring principle is the same. The flavour, however, may be, and, we believe, is, different. In either case the colour is produced by the roasting of *saccharum*; but as the whole of the malt is not *saccharum*, the roasting to blackness mixes the colouring part with a large proportion, probably a half, of common charcoal. The charcoal will, no doubt, subside, but its previous effects are unknown, and, accordingly, some of the principal brewers have never used black malt; and none of them, we believe, brew either their keeping porter or their brown stout without the admixture of brown or amber malt. Private families may colour and flavour as they please; and we are persuaded that, in making porter, they will find the charring of sugar the most convenient. For this purpose a quantity of brown sugar, moistened with water, may be put in a frying-pan, the bottom of which should be covered to about an inch deep. This is then to be roasted on a fire, and stirred for some time, until it inflame spontaneously. The flame, after it is judged (from practice) to have burnt long enough, is then extinguished by a cover; and water is added to the pitch-like residue until the whole has the consistency of treacle, when it is put into a bottle or can for use. This colouring is afterwards to be mixed with the worts in the copper in such quantities as are required.

Mr. Richardson's instructions for the brewing of porter, if literally followed, would produce a clean and full-tasted liquor; but they are deficient in some particulars, with respect to the after-management, especially in the London practice. It may be here noticed, by the way, that the quassia, or aloes, which he recommends cannot be used with impunity; and, therefore, the quality and quantity of the hops are now more strictly attended to than in former times. The gravity, too, differs much from his example; for we believe that there is seldom any gyle now made of a less weight than twenty pounds. We may add that the heat of the tun is now less attended to. The criterion for cleansing is the attenuation; and when that has sunk to ten or eleven pounds, (which is usually in less than forty-eight hours)

the operation is begun. By this time the heat is generally about 75°, being pitched at 65°; and a degree of heat, in a good fermentation, usually accompanies a degree of attenuation.

About five-and-twenty years ago, when we first attended to the brewing of London porter, it was the practice to keep very large stocks of that article for twelve or eighteen months; for the purpose, as was then thought, of improving its quality. The beer was pumped, immediately after it was cleansed, into store-vats, holding from five to twenty gyles (brewings) each. The usual size was between four and six thousand barrels; but one, the boast of its brew-house, contained eighteen thousand, and was said to have cost ten thousand pounds. The porter, during its long repose in those vats, became spontaneously fine, and, by a silent fermentation, lost the greater part of its remaining *saccharum*. Its bitter, also, grew less perceptible, and the liquor was transformed into *good, hard* beer. This was softened by the publican to the taste of the customer, by the addition of such as was *mild*, that is, newly brewed; but little of this milder sort was at that time required. The taste of the metropolis has since undergone a great change; so much so, that more than half of all that is brewed is drunk before it is six weeks old. The demand for mild beer is still increasing; and we cannot better detail its progress, and explain the nature of the mixtures of *mild* and *stale*, than by copying the information given by Mr Barclay (of the firm of Barclay, Perkins, and Co.) to the Committee of the House of Commons, in the year 1818:—

"What quantity of beer do you now brew annually?—About 300,000 barrels.

"Is sour or stale beer used in your vats with new beer, to your knowledge?—To answer the question correctly, I should state, that every publican has two sorts of beer sent to him, and he orders a proportion of each as he wants them; the one is called *mild* beer, which is beer brewed and sent out exactly as it is brewed; the other is called *entire*, and that beer consists of some brewed expressly for the purpose of keeping: it likewise contains a proportion of returns from publicans; likewise the beer which we receive from public-houses, which has been brewed by other brewers, and which have changed into our trade (as it is our plan always to clear the cellar

of a publican before he begins to draw our beer); and likewise a portion of the beer the bottoms of vats; the beer that is drawn off from the pipes which convey the beer from one vat to another, and from one part of the premises to another; this beer is collected and put into vats: it also contains a certain portion of *brown stout*, which is twenty shillings a barrel dearer than common beer: it also contains some bottling beer, which is ten shillings a barrel dearer. I should observe, that the beer returned from the publican is always examined by a class of clerks called coopers, and, as far as they can possibly judge, if there is any admixture of any kind or sort, if it has been weakened, it is put aside, and in some instances been thrown away, and the person not allowed for it; but, in general, there is an examination made of the beer upon being returned. Now all these beers united are put into vats; and it depends upon various circumstances how long they may remain in those vats before they become perfectly bright; when it becomes bright it is sent out to the publicans for their *entire* beer, and there is sometimes a small quantity of mild beer mixed with it.

"Do you ever buy *sour* or *stale* beer of any other persons than the publicans whom you serve?—The Committee will observe by my preceding answer that the publicans require a certain quantity of this stale beer, which they mix with the mild beer, according to the taste of their customers, some preferring it new, and some older; but I should observe, that the taste of the town is continually changing, so that now they use but very little of this entire beer; and if the trade of a brewer increases very rapidly, he may not have sufficient stale beer of his own to send to his publicans, and that was the case with our house some years back; and I believe since, in two or three instances. Upon those occasions we have bought stale beer of other brewers, but in doing that we have been extremely careful in selecting only that of the best quality.

"Is that stale beer *sour* beer?—That beer has not got the acetous fermentation upon it; if it had it would not be fit for use. It is what is commonly called *hard beer*.

"You have stated that there are a number of beers mixed together; have you any fixed proportion in that mixture?—It is the remnants of everything; and I have described to the Committee

what it consists of, and that a part of those remnants are of a very superior quality, particularly when they come to the bottom of the brown stout.

"What proportion of the whole number of barrels sent out would those remnants form?—About one tenth: we send out about one tenth of entire, but that is not consisting of remnants, because, I believe I stated before, that part of it is beer brewed and kept for that purpose.

"What proportion might the remnants form of the whole 300,000 barrels?—Our return is about 10,000 barrels a year, which includes beer brewed by other brewers, and which have been taken of publicans who have come into our trade, a good deal of which is mild beer.

"Is the beer that is composed of remnants wholesome and good liquor?—Perfectly so.

"Is it absolutely necessary that a publican should have some of these remnants to mix it for the taste of his customers?—I should think so. It has been the constant practice as long as I have known the trade; and in former years they used to draw more of that *entire* than they do now.

"Is not that *hard* or *stale* beer mixed to give the porter the appearance of age at once, which formerly was allowed to be matured by time?—It must have the effect of making the beer taste older; but I should think that the beer which was formerly kept a twelvemonth would not be drank by the public; their taste is for mild beer.

"Does the use of stale beer effect a quick sale in the trade, and consequently a quicker return?—I do not see how the publican could well please his customers unless he had the means of making his beer either stale or mild as they wish for it. The Committee will see that if the brewer had not this vent for selling his *return-beer*, the price of beer must be considerably higher if he is to throw this beer away, which amounts altogether to near 20,000 barrels in our house alone."

CHAPTER VIII.

OF SCOTCH ALE.

THE distinguishing characteristics of Scotch ale, are paleness of colour, and mildness of flavour. The taste of the hop never predominates, neither in its stead do we discover that of any other

ingredient. It is perhaps more near to the French pale wines, than any of the other ales that are brewed in this country. Like them, too, it is the result of a lengthened fermentation.

The low heat at which the tun is pitched, confines the brewing of Scotch ale to the colder part of the year. During four or five of the summer months, the work (except perhaps in some houses for table beer) is completely at a stand, the utensils are limed down, and the greater part of the workmen discharged. No strong ale is either brewed or delivered.

The Edinburgh brewer is particularly nice in the choice of his malt and hops. The former is generally either English, or of his own making from English barley; and the latter Farnham, the finest East Kent, or a mixture of both. The yeast (or *store*, as it is termed) is carefully preserved, and measured into the gyle-tun, in the proportion of about three gallons to twenty barrels of wort.

The Scotch practice is to take only one mash, and that pretty stiff, for strong ale, making up the quantity of wort (*length*) by eight or ten subsequent sprinklings of liquor over the goods, which are termed *Sparges*. These sparges trickle successively through the goods, and wash out as much more of the saccharine from the mash, as may suffice for the intended strength of the ale. In this manner, specific gravities may be obtained much higher than could be done by a second mash, which always requires a certain portion of liquor before the goods can be made sufficiently fluid. If we suppose this necessary portion of liquid in a particular mash to be fifteen barrels, it would be found, on trial, that these fifteen barrels, when drawn from the mash-tun, would not contain nearly so much saccharine matter as might have been extracted by ten successive sparges of a barrel each. The reason of this will be obvious, if we recollect that the grains always remain wetted with wort equivalent in strength to that of the wort last drawn off, and that the quantity remaining on the goods is about three-fourths of a barrel to a quarter of malt. The gravity of this imbibed wort will, in the one case, be equal to that of the second mash; but in the other, will be reduced to that of the tenth sparge, or washing. Mr. Richardson, so often quoted, condemns this practice; but, in doing so, we know that he labours

under a mistake. "What power," says he, "or what time, has a fluid to extract, which is sprinkled over the surface of the materials, and immediately trickles out below, without being allowed a stationary moment for *infusion*?" We answer, that in malt (and it is only of malt brewings that we now speak) the *infusion*, if properly conducted, is finished with the *first mash*; and that nothing more is necessary than to draw out from the goods, in a pure state, that saccharine matter which the first infusion has set free. But the question with us does not depend on theory. We have brewed strong ale for years, without following it either with table beer or returns, and we have, in all cases, drawn as much from the malt as we could have done by repeated mashings. The only objection to the *sparging system* is the loss of time.

The first part of the process is to mash with liquor heated to 180° at least,* and generally to 190° , varying with the dampness of the malt. According to Dr. Thomson, the best brewers take the lower heats, but this is doubtful. After mashing from twenty minutes to half an hour, that is, until every particle of the malt is in contact with the liquor, the tun is covered, and the whole allowed to *infuse* about three hours, when it is drained off into the under back, or (what is far better) into the wort copper.

After the first wort is run off, a quantity of liquor (generally a barrel), at the heat of 180° , is sprinkled equally over the surface of the goods. To prevent the liquor from dashing on one part, it is usually received upon a circular board, about three feet diameter, which is swung over the centre of the mash-tun; and, being perforated with small holes, allows the water to descend in a shower. The board being hung on cords, is moveable by the hand over every part of the surface of the tun. When, as generally happens, the cock of the liquor-copper is not high enough to carry the liquor to the board, a separate cock is inserted in the side for that use only. Other means may be adopted to answer this purpose of sprinkling, the object being to spread the liquor, equably, in a shower over the whole surface of the goods, as if from the rose of a watering-pan.

When the barrel (or other quantity)

* It is here to be observed that we merely record the practice; not our own opinion of its propriety.

of liquor is thus let in upon the goods, the cock of the mash-tun is opened, so as to let it off, as in the case of an ordinary mash. Some brewers, instead of the common outlet of the mash-tun, have three or four small cocks inserted in different parts of the bottom, from the fear that a single cock might draw the filtrating liquor to one point, and thereby create a crack in the goods, instead of leaving the whole of the liquor to descend in one horizontal stratum.

When the first sparge is run off, or nearly so, which may be in twenty or five and twenty minutes, another of equal quantity is put on the goods, in the same manner, and thus, successively, until the whole of the sparges, when mixed with the first mash worts, show that gravity which is desired. The strong ale worts are then completed, and a mash is made to search the goods either for table beer, or a return, as the trade requires. This mash, however, is not necessary as a saving of extract; for the whole of the saccharine matter of the malt may be exhausted, as well as any required gravity of wort produced, by means of sparges alone; but there is an opinion, probably not ill founded, that the last weak extracts are less fitted for fine ale. The making up of strengths from the coolers formerly explained, is here anticipated, being regulated by the saccharometer in the under back, or wort-copper; for practice soon teaches the increase that is produced by the boiling. It may be here noticed, that after the first sparge at 180° , it is customary with some brewers to reduce the others gradually, so that the last is perhaps 175° or 170° .

All rankness of flavour being carefully avoided in this species of ale, the quantity of hops seldom exceeds four pounds to the quarter of malt; and the bitter thus created being too slight to cover the taste of ruder ingredients, we believe that the Edinburgh brewers have been less the prey of travelling druggists than their brethren of the south. A little honey to add to the sweet, and a few coriander seeds or other aromatics to assist the flavour, are, as far as we have learnt, the amount of the sins of which they have been accused.

The manner of boiling the worts does not differ from the directions of Mr. Richardson; but when they arrive at the gyle-tun, the process of brewing is no longer the same. The first heat of fermentation, in the Scotch method, is as

low as possible, consistent with the action. The favourite heat is 50° , a point at which chemists have generally asserted that the vinous fermentation could not exist, but 45° and 46° are by no means uncommon in the manuscript brewing-books that now lie before us. Even in the coldest weather, the lowness of heat is not to be feared, provided the brewery be in full work. The fermentation sometimes continues for three weeks, and a fortnight would be a pretty fair average. Were the brewings made three times a week, seven or eight working-tuns would thus be generally in play; and these being in the same room, some of them at 12 or 15° of increased heat, would create an atmosphere for themselves.

The quantity of yeast formerly mentioned is generally sufficient, but, in some cases, an addition is made a day or two after, if, in the judgment of the brewer, it appears necessary. The least quantity that will carry forward the fermentation to the required point is always preferred; and, to assure that purpose, the tun is roused twice a day (morning and evening) to prevent its becoming too languid. This rousing is continued until the ale is nearly ready for cleansing.

The rule for cleansing differs from that given by Mr. Richardson. It is an application of his saccharometer, of which he himself was not aware. The attenuation is attended to daily, and, towards the close of the operation, twice a day. While the heat is increasing, the attenuation proceeds; that is, the weight of the worts continues to diminish. After a certain time, the heat has reached its highest point, and begins to lessen. It is here that we are directed by Mr. Richardson to trust to the *smell*; but this *smell* merely informs us that carbonic acid continues to be evolved, and the same circumstance is, in consequence, indicated by the saccharometer: for as long as any such evolution of gas exists, so long will the weight of the worts continue to diminish. When the progress of the attenuation is so slow as not to exceed half a pound in twenty-four hours, it is prudent to cleanse, especially if the attenuation is already low; for it might otherwise happen, that the gas being too weak to buoy up the now close head of the tun, the yeast might partially or wholly subside, and the ale would become *yeast-bitten*: it would receive that disagree-

able taste which the head had acquired by too long exposure to the atmospheric air.

When the ale is cleansed, the head, which has not been disturbed for two or three days, continues to float on the surface, till the whole of the *then* nearly pure liquid is drawn off into the casks; and this is considered as a preservative against the admission of the atmospheric air: for the Scotch do not skim their tuns as the London ale brewers so generally do. The ale thus cleansed does not require to be placed on close stillions. It throws off little or no yeast, and a tub placed so as to catch any little overflow of the scum that arises is quite sufficient. The fermentation is almost finished in the tun; and it is not the wish of the brewer that it should proceed much farther.

The strength of Scotch ale, when it deserves the name, ranges between thirty-two and forty-four pounds weight to the imperial barrel, that is, of a specific gravity between 1089 and 1122, according to the price at which it is meant to

be sold. The general mode of charge is by the hogshead (about a barrel and a half), for which five pounds, six pounds, seven pounds, or eight pounds are paid, as the quality may warrant; the strength for every additional pound of price being increased by about four pounds per barrel of weight.

In a good fermentation, there seldom remains above a fourth of the original weight of the wort at the period of cleansing. Between that and a third is the usual attenuation. If above a third remains, the taste is generally mawkish, and it is to be feared that the acetous fermentation will commence, before the time in which the ale might be expected to improve. Of the less sensible process of attenuation which goes on afterwards in the casks, we have already spoken when treating generally of the "Vinous fermentation." Scotch ale soon becomes fine, and is seldom racked, at least for the home market.

We shall now transcribe the notes of a few actual brewings, in order to illustrate the rules above written.

No. 47. MARCH 10th, 18—. MASHED FOR STRONG ALE

13 Bolls (about 10 quarters) of Malt, T. L.*—42 lbs. Hops, East Kent.

Hour.	Min.		Bar.	Heat.	Grav.	
6	—	Mash	17	190°	—	7 o'clock Worts in Coolers.
9	—	Set tap	—	—	36	18½ Barrels X. Gravity 36 = 666
9	30	Sparge	1	180	35	6 ——— T. ——— 10 = 60
10	—	do.	1	180	34.2	10) 726
10	20	do.	1	180	35.2	
10	45	do.	1	176	35.6	Lbs. weight extracted per quarter 72.6
11	10	do.	1	178	35	<i>Fermentation.</i>
11	35	do.	1	178	34	Mar. 11. M. 5. Pitched at 50°. Yeast 3 Gals.
12	—	do.	1	175	35.7	Heat. Gravity.
12	20	do.	1	175	32.6	Mar. 12 50° 36
12	45	do.	1	174	27.5	15 52 33
1	10	do.	1	173	25	16 54 30
1	40	All in Copper.				17 56 26
		Mashed for Table Beer.				18 58 23
			8	160		19 60 20
2	20	Set tap.	8	—	7	20 62 17
4	10	Cast Copper, Ale.				21 63 15
						22 62 13½
						23 62 11½
						24 61 10½
						25 61 10
						26 60 9½
						cleansed
						with salt and flour.

* The initial letters of the Maltster's name.

It may be observed, with respect to the left-hand portion of these tabular statements, that the *gravities* are taken as *averages* to direct the brewer in the number of his sparges, and are not minutely correct. The weights are those of worts, warm as they issue from the mash-tun; and, even in those small *sparges*, it would make some difference if taken from the former or the latter part of each running. The sparges themselves, too, may not be made with extreme nicety with regard to the quantity. The whole of the process, however, is easily acquired by practice, without which, in the manipulations of the arts, science is of little avail.

CHAPTER IX.

OF SCOTCH TWOPENNY.

AT and previous to the beginning of the eighteenth century, every publican in Scotland (being every man who chose to embark in the trade) brewed his own ale; and the resort to his house depended on the quality of his liquor: which, when thunder or witchcraft did not interfere, was generally excellent. The strong ale was reserved for holidays and the tables of the great; but the *twopenny* (so called because it was sold at twopence the Scotch pint*) was so much esteemed as a national beverage, that it was inserted by name, and guarded by peculiar privileges, in one of the Articles of the Union. Another Article, however, in the same Act, secured to the Scottish brewery an Exchequer Court; and this, conjoined with the enormously increased malt duties, so lessened the exhilarating qualities of this ancient ale, that it has now lost its fame. In its stead, a kind of small drink is brewed; but it is destitute of all the qualities which were so often celebrated in Scottish song, and is scarcely superior to the trash termed *table-beer* in the work-houses of the metropolis.

When the Scotch twopenny was the boast of the nation, saccharometers were unknown, and thermometers had not been heard of by the brewer. He shaped his course by habit, and with surprising accuracy, as blind men are often known to do. When we first knew the article it had much degenerated; but even then it must have weighed from fourteen to

sixteen pounds per barrel, as far as we could judge from the lengths which they drew. The quantity of hops seldom exceeded two pounds and a-half to the boll of malt, or about three pounds to a quarter. This was forty years ago, and the old tapsters were then accustomed to tell tales of how they managed to brew ale without hops in their youth.

The boiled worts were usually cast into what were then called half-barrel easks, for few had coolers*; and the gyle-tun (which was often the mash-tun also) was first started, or pitched, at about blood heat. This was done with a single half barrel, or less, for the purpose of *chipping* the worts; and the tun was afterwards filled up, by half-barrels at a time, when they had cooled to the requisite degree. The heat of the fermentation was regulated by the appearance of the yeast head, and great care was taken that it should neither be scalded nor chilled. When the smell of the tun became strong, the ale was cleansed into half-barrels, and discharged its yeast into tubs. But the whole brewing was never so fermented; for a great part, often one half, was preserved (in the easks in which it had been thrown from the copper) in the state of worts.

On reading this account of turning the worts boiling hot into the easks, and allowing them to remain there for several days, the modern brewer will immediately exclaim that the ale must have been *foxed*, a term which he gives to an incipient stage of putrefaction, which is supposed to be attended with a smell like that of the animal whose name it bears. We can assure him, however, that this accident was very rare, although it would probably be an inevitable consequence of the same practice in many other breweries. The great preventive was cleanliness. The easks were repeatedly washed and steamed with hot water before every brewing; and, in order that not a speck of dirt should be left, the bung-holes were cut square, and large enough to allow the brewer to put in his arm, and scour them completely with a *heather rinse*. The large size of the holes, as well as the highly fermenting state of the liquor, rendered it inconvenient to use corks; and, therefore, when the ale was sent

* The old ale pint was nearly two English quarts.

* They held about sixteen English ale gallons.

out in casks, it was kept in the barrels by means of covers made of clay. "It is in allusion to this practice that Shakspeare speaks of tracing the dust of Alexander till it be found stopping a bung-hole." *

After that part of the ale which was cleansed had discharged the greater portion of its yeast, a pailfull was drawn from every cask, into other casks, and the vacancy in each was replaced by a pailfull of the reserved wort. The fermentation was thereby renewed, and the operation was repeated once a day until all the reserved worts were expended; and those were so proportioned as to keep the fermentation *alive* until the succeeding brewing. This operation was called *handling*; and it was in this slowly fermenting state that the ale was sent out to the customers, in casks, or sold in flaggons. We have seen ale preserved, by this means, for nearly a fortnight, in summer weather, without the least perceptible tendency to acidity. Ale, in Scotland, whether strong or weak, was always bottled. In the kind of which we now speak, the cask was allowed to be undisturbed, before drawing off, for twenty-four hours, or perhaps twice that period, according to the length of time which it was to remain in the bottles before ripening. It was generally expected to be very brisk in the course of a week.

With respect to unlawful ingredients, we have already said that the Scotch are less to be complained of than their brethren of the South. The legislature, however, has, it seems, always thought otherwise; for, in addition to the caveats which are addressed to the whole island, there are some which are peculiarly directed against the brewers of Scotland. The following extraordinary prohibition, for example, is still in the Statute Book, and is regularly promulgated under the authority of the Excise:—

In Scotland.—By the Act Will., Parl. 1. Sess. 6. c. 43. no salt shall be made use of in brewing beer or ale, whether in washing and seasoning of vessels, or any other way whatever, under pain of confiscation of looms and vessels, with the liquor found therein, attour the loss of his freedom, if the transgressor be a burgess, and the being incapable to

use the trade of brewing thereafter. The looms and vessels shall be given to the informer, who shall be free from the said penalty, albeit he have been a servant or accessory."

To prevent ale or beer from *foxing*, we are convinced that no cleansing material could be better than salt.

CHAPTER X.

OF BURTON ALE.

WE have formerly given Mr. Richardson's instructions for the brewing of this liquor; but we acknowledge that we have never been able to produce the flavour and permanent sweetness of Burton ale by following that gentleman's directions. The indiscriminate prohibitions of the Excise rise up before us, as they probably did before Mr. Richardson. They may have arrested his pen; but they shall not ours. We write not for the common brewer, but for the private gentleman, whose operations are unfettered. We will not say that the plan which we shall here point out is followed by the brewers at Burton, but we know that ale very like to theirs, in all respects, has been the result of this process.

Two ounces of salt of steel, dried until it becomes white, is infused into twenty barrels of liquor before mashing, that quantity of liquor being usually allowed for the first mash of ten quarters of malt. The use of this small portion of salt of steel is supposed to assist the extract; but we think that it has, more probably, been introduced to catch any incipient dose of oxygen which might favour the production of acidity. Its value may be questioned; but this small proportion, at any rate, is harmless.

Twenty barrels of this liquor is then turned upon the ten quarters of malt, in the ordinary way, upwards, through the false bottom. The heat is between 165° and 170°,—generally nearer the former. The mashing is continued about an hour, after which it is allowed to infuse about an hour and a half longer; the goods being covered with a sack of dry malt to preserve the heat.

When the first mash is run off, from ten to fifteen barrels of liquor (according to the proposed strength) is run over the goods at the heat of 185°. This

* Booth's Analytical Dictionary of the English Language.

is allowed to infuse two hours, when it will have sunk and mixed with the goods, without having been mashed. This differs from the Scotch practice by making up the length with one, in place of many sparges. Practice enables the brewer to fix the quantity of this second liquor; but he runs some risk of error in untried malts, while the Scotch brewer is always safe by weighing the wort in separate and successive portions.

This second liquor being run off, the strong ale worts are all extracted; and *table beer*, or a *return*, is made to exhaust the goods. It is usual, in the case of table beer, to cap the goods with a quantity of dry malt, which is understood to be necessary in order to procure the requisite strength. We believe that this practice (of which we do not approve) originated from a different cause. There was a time when the Excise objected to *party-gyles*, that is, to making two kinds of beer from the same malt; the *capping* was introduced to make (formally) a separate brewing, and was continued from the influence of custom. The least quantity of capping answered the purpose, so that it *covered* the goods, the strength being regulated by the quantity of liquor in the table-beer mash. This mash is generally made at 150° of heat, and allowed to stand about an hour:—but we return to the strong ale.

The quantity of hops is usually about six pounds to the quarter of malt, and the time of boiling from two to two and a half hours. From ten to fifteen minutes before turning off, a quantity of honey, at least equivalent to a pound per barrel, is put into the copper. The honey is previously dissolved in scalding-hot liquor.

With respect to the fermentation, the tun is pitched at sixty-four or sixty-five degrees, with a pound of solid yeast per barrel. The first head is skimmed to rid the wort of the impurities which usually float upon the surface. After this the tun is generally kept covered, except when it is roused, which it is, twice or thrice a day. In from forty-eight to sixty hours it ought to rise to eighty degrees, or more; and when the

gravity is about twelve pounds, it is usual to put half a gallon of bean flour and four ounces of sal prunella, previously well roused together in a portion of the worts, to every twenty barrels. The whole is then cleansed into barrels, which are filled up every two hours until they cease to discharge any yeast. Should the fermenting tun fall in heat, some recommend that two ounces and a half of jalap should be added for every twenty barrels of the wort.

Immediately after the casks have ceased working, six ounces of unburnt, but bruised, sulphate of lime, mixed up with an ounce of powdered black rosin, (both previously whisked in a small quantity of the ale,) are put into each barrel. Over this a small handful of half-boiled hops is also inserted; and the cask, being then quite full, is closely bunged up, having a gimlet hole, closed with a peg, at the side of the bung-hole, as an occasional vent for the escape of the carbonic acid which may afterwards be generated. The rosin and hops preclude the access of atmospheric air; and the sulphate of lime, which in a short time disappears, is said to prevent any secondary fermentation,—the usual forerunner of acidity. The honey is also understood to ward off the acid fermentation. Honey and water, especially when boiled, does not readily complete its attenuation, and hence it is supposed to answer all the preservative purposes of hops in the beer of Louvain.

The strength of the Burton, like that of every other species of ale, varies with the price. The qualities are seldom more than two; the one weighing from 30 to 32 pounds per barrel, and the other somewhere between 35 and 40, differing in the several brewhouses and with the demands of their customers. The latter, however, is accounted a *maximum* strength, and exceeded only in rare instances. Below 28 pounds the preservative quality, so peculiar to this sort of ale, is not to be depended on. The charge is usually by the gallon, because the sizes of their casks are various.

The following are notes of a brewing conducted according to the preceding directions:—

APRIL 27th, 18—. MASHED FOR BURTON ALE.
Malt 6 quarters.—Hops 36lbs.—Honey 20lbs.—S. Steel 2oz.

Hour.	Min.		Bar. Liq.	Heat.	Bar. Wort.	Grav.	
7	—	Mashed.	12	165	—	—	April 28, M. 8. Worts in Tun.
10	—	Set tap.	—	—	—	—	12 Barrels X. Gravity 34.8 = 417.6
—	20	Spent.	—	—	7	35	10 Barrels Return in Copper, Gravity 6.2 = 62
—	—	Run on.	9	180	—	—	6) 479.6
12	30	Set tap.	—	—	—	—	Extract Gravity per Qr. = 79.9
—	50	Spent.	—	—	9	22	
1	—	In Copper.	—	—	16	27.7	
—	—	Mashed for Return.	12	165	—	—	<i>Fermentation.</i> Yeast 10 lb.
3	30	Mixed Honey.	—	—	—	—	Heat. Gravity. April 28 66 34.8
4	—	Cast Copper.	—	—	13	—	Morning 29 70 28
Return and Hops in Copper.							— 30 75 20
							Evening 10 80 14 cleansed.

In two days the ale had ceased throwing off yeast: and when it had stood two days more with occasional fillings, it was bunged up, after receiving a handful of half-spent hops, &c. as in the directions. This ale was kept through the summer; and, in the following September, it had become quite pure, and was bottled at a gravity of six pounds. In a month afterwards it became pretty ripe, and was well liked.

CHAPTER XI.

OF SMALL BREWINGS.

ALTHOUGH it is our wish that the Art of Brewing should be understood in every family of the kingdom, it, nevertheless, in its simplest form, requires manipulations that cannot be communicated in a few detached sentences, like the receipts of a cookery book. A certain degree of practice, however small, is necessary before general directions can be of any value; and, notwithstanding that we have endeavoured to be extremely plain, we fear that our observations would scarcely be understood by one who never saw a mash-tun, nor witnessed the production of a malt extract. It is, therefore, only to such as have already been present at private brewings, however well or ill conducted, that we are enabled to address ourselves; and to those persons we would recommend the attentive perusal of what we have

already written, before they place their confidence in the succeeding examples.

For those families whose consumption requires, and whose means enable them, to brew two or three quarters at a time, our instructions may be simplified. Let them take any of the examples already given (according with the sort of beer, or ale, which they want) and diminish the measure of liquor in the mash, and the weight of the hops, as there specified, in proportion to the quantity of the malt which it is intended to brew. It would be well to keep to the same time of infusion; but, in that case, the heats of the mashing liquor should be four or five degrees higher; because, in small brewings, the mash-tun is apt to become so cool as to risk acidity in the worts. A like observation may be given respecting the fermentation. It must begin higher by five or six degrees; and it will be discovered, that under no circumstances will the heat of the tun rise so far above its first pitch as it usually does in large gyles. The criterion for cleansing and the previous proper attenuation to be aimed at are the same. In the case of porter, it will be more convenient to use pale malt, and give the colour (and consequent flavour) by means of sugar, burnt as directed at page 51. The aloes or quassia, which may be here used with impunity, will not only be a saving, but will be preferable to giving the whole of the bitter with hops.

In making strong ale, the private brewer is generally obliged to use more malt than he otherwise would; because, having no means of taking the advantage of a *Return*, he must make a quantity of small beer, whether it is wanted or not, for the purpose of searching the grains. In such a case, either the Scotch or the Burton system would be the best. His worts might thereby be made sufficiently strong without any loss of extract, and might be divided, as they passed from the tun, into any requisite strengths; either making the whole strong ale, or a part of it table beer, in such proportions as might be found convenient. The saccharometer would form the best assistant; and it would be extremely advantageous to quality and flavour, as well as to preservation, that the potency of the ale should be increased by the addition of honey. The quantity of this ingredient is to be regulated solely by taste; the mixture forming the link between *Malt Liquor* and *Mead*.

The history of the last-mentioned article is evidence of the baneful effects of the excise upon manufactures. The duties upon *Mead* were increased, from time to time, until it could no longer be made for sale. The duties, prohibitions, and penalties, still remain in the Statute Book; but we do not know that there now exists a single person liable to their inflictions. It is melancholy to see its expiring effort, in the excise accounts for 1808:—"The gross actual receipt in money" for duties on *Methugglin*, or *Mead*, during the whole year, is there stated to have been "one pound eleven shillings and six-pence." The quantity, on which this duty was charged, could not have exceeded twenty-one wine gallons; and the maker must have paid, besides, two pounds for a license. It might be supposed that these prohibitory duties, upon the manufacturer for sale, must be advantageous to private families who pay nothing; but in the present instance it is otherwise. Good mead cannot be brewed, even without duty, at less than five shillings a gallon, being equivalent to a shilling the wine bottle. It requires to be made in quantities of ten gallons at least, and is seldom fit for bottling in less time than a twelvemonth. With this outlay and care it once rivalled the wines of France, but the rich are contented with the latter, for which they are able to pay; while the poorer classes,

who, on occasional merry-makings, or in sickness, might prefer it to a bottle of adulterated port, can purchase it nowhere, and are unable to lay in a stock for themselves. This is one among a thousand greater instances of the price which the people pay for the wars they have been so fond of. Some directions for making *Mead* will be found in the *Treatise on Wine-making*, to which subject it more immediately belongs.

The midland counties of England have generally been famed for their malt liquors. That of Burton has already been particularly described; but those of Nottingham and Birmingham also find their way into the London market: indeed, any sort of country ale is preferred to what is usually manufactured, under that name, in the metropolis. Private brewing, too, is more general in the district above-mentioned, than in other quarters of the island; and the following description of the practice of a private family of our acquaintance in Worcestershire may be considered as generally prevalent in that and the neighbouring counties. It is obviously capable of improvement in regard to the saving of expense; but, in quality, the ale is by no means objectionable.

1. FOR GOOD COMMON ALE.

The strength of this ale was fixed to twelve gallons for every bushel of malt, and two bushels was the quantity usually brewed at a time; for which one and a half to two pounds of hops were allowed, according to their quality and the season. The Worcester hops were preferred as being milder in flavour than the Sussex or Kent. The malt was ground, rather coarsely, in which case it was supposed to drain better than when too fine; and the drainage was made to pass through a small cap-like wicker basket, called a *Betwel*, which was placed on the bottom of the tun so as to cover the entrance to the draining cock, or spiggot, as the case might be.

When every thing was prepared, and the liquor had begun to boil, the furnace door of the copper was thrown open, and the boiling having just ceased, as much of the hot liquor was run into the mash-tun as covered the bottom to the depth of an inch, or an inch and a half. About half a bushel of the malt was then put in, and stirred intimately with the liquor, until it was completely wetted. Another quantity of the hot water, sufficient to wet a second half bushel of the

malt, was then let on; and this remainder of the first bushel was put into the tun, and the whole stirred together until every particle of the malt was supposed to be wet. The same process was carried on, by half a bushel at a time, mixed with continually added liquor, until the whole mash became completely soaked. A gallon of the liquor (as much as might have been contained within the draining basket or *betwel*) was then drawn off from the bottom of the tun, and thrown upon the top of the goods, which, after being covered with a sprinkling of dry malt, and *marked with a cross*, drawn over the surface with the end of the mashing oar, were allowed to rest, for the purpose of infusion.

When the mash had stood three hours, it was let off slowly into a tub (or under-back) upon the hops, which had been previously steeped in hot water; and, after the draining was completed, an additional quantity of liquor (about the same heat as before) was laded regularly over the goods until the whole were as wet as at the first mash. This second infusion was allowed to stand an hour, when it was also run off, and transferred, along with the first worts and hops, into the copper for the purpose of being boiled. The quantity of worts required to produce the twenty-four gallons of ale (which, to allow for waste in boiling, might be about thirty gallons), was made up by sprinkling hot water over the goods, while the mash-tun was allowed to continue slowly draining.

When the worts had boiled in the copper for an hour, they were cast into wide tubs for the purpose of cooling. These being of different sizes, cooled unequally; but care was always taken not to mix hot worts with cold. A few quarts of the worts, when about milk warm, were stirred up with a quart of good fresh yeast, in the bottom of the fermenting tun, at which heat they rose into immediate action; and the remaining worts (except a small part) were added as soon as they were considered to be sufficiently cool.

When the head of the tun got very strong, and before it had begun to sink, the ale was cleansed; but previously to this being done, the bottom of each cask was covered about an inch deep, with the reserved worts above-mentioned;—we say the *bottom*, because the casks were placed upright, and discharged their superfluous yeast down the sides, from a wide tap-hole in the upper end.

In two or three days the fermentation generally subsided, so as to allow them to be loosely bunged; and in about a week more, after inserting a handful of half boiled hops in each cask, and filling it up, it was bunged up close, having a vent-hole and peg to loosen if necessary. In four months the ale was judged ready for tapping, and was drunk from the cask without bottling. This sort of ale is brewed, of course, at such times, and in such quantities, as to ensure a regular succession of four or five months old, keeping in view that the spring and autumn are the best seasons.

2. FOR STRONG ALE.

The quality of the strong ale is calculated from the *length* that is drawn from the bushel. Some gentlemen make it a rule that a gallon of malt shall produce a gallon of ale; while others draw only five or six gallons from the bushel. The brewing of which we have now to speak consisted of twelve bushels, and from this about seventy gallons of strong ale were made. For this purpose about eighty gallons of wort were drawn from the goods, in the same manner as in the common ale. The hops (twelve pounds) were boiled with the worts an hour, or an hour and a quarter; and about the middle of that period a *lump of salt* (perhaps a pound) was thrown into the copper. Salt is also put, by some, in the common ale, in the same manner.

During this time, as much liquor was infusing with the goods as produced, when boiled and fermented, eighteen gallons of *very good* table beer. The hops of the strong ale were more than sufficient for the small, and part was usually kept out.

The fermentation was begun and conducted in the same way as in the last article, only with a larger portion of yeast, on account of the greater strength of the worts. The time in the fermenting tun was longer, the cleansing being guided by the appearance of the head, as it began to thicken. In cleansing, there was no reserved wort used, as in the preceding brewing.

In about three weeks after cleansing, the ale was racked into other casks; and a quart of ground malt tied in a clean linen bag was put into each. A handful of half boiled hops was also put in, and the bung made firm. Some persons put horse heans, either bruised or whole, in place of the malt, and also a few egg shells and a pound of loaf

sugar to a barrel, with the view of better preservation.

This ale was kept six months in the cask before it was tapped. It was then bottled, and ran no further risk of acidity, although kept for years. October or November is accounted the best season for brewing, because the six winter months are understood to be most favourable to the keeping of ale that is newly brewed. When it has passed those months, it runs less risk of acidity during the succeeding summer, in the case of its continuing in the casks.

On reviewing the preceding directions, it will be observed that much is left to the experience of the brewer, which, from the want of instruments, cannot be communicated to the reader. The heat of the mashing liquor was probably above 190°, but this is left to conjecture. It must have varied with the heat of the atmosphere, but in the worst direction; for, in cold weather, the liquor would be at a lower when it ought to be at a higher temperature. The heat of the fermentation must have been liable to the same accidents. The proper period for cleansing, too, must have been very difficult to ascertain, there being no mode of discovering the attenuation; and in consequence, under such management, the strong ale might be ready for bottling two or three months sooner, or it might be protracted two or three months later than the period intended.

The mode of mashing (akin to the Scotch *sparging* system) is capable of drawing out the whole strength of the malt, were it not for two prominent errors: one of which is the consequence of the other. The want of a false bottom makes coarse grinding necessary to enable the worts to work their way to the basket. Without either fine grinding, or crushing, the malt cannot be sufficiently searched; and, unless the sparges are allowed to descend in horizontal strata, we leave one side of the mash-tun to be less acted upon than the other. We are well convinced that, in the fore-mentioned examples, and especially in the second, one-third of the extractible saccharum of the malt was left in the grains.

In the details of which we now speak, the reader's attention was particularly directed to the *cross* that was drawn on the surface of the goods. This *sign of the cross*, in those counties, is universal, although no one knows why. The

Protestants consider it as a remnant of Popish superstition. There is, however, no superstition in the case. It is a useful proof of the perfection of the process. After the mashing is finished, and the goods strewed over with dry malt, the cross can only be fairly drawn when the whole of the goods are completely broken. If any knots or lumps remain, being lighter than the rest, they rise to the surface; and meeting the rod by which the cross is drawn, they will break the continuity of the line. A similar practice is observed by the maltsters in Scotland, and perhaps in other places. After a floor has been turned, the maltman makes a *cross* on a corner of the surface with the end of a shovel, the appearance of which shows whether the grains of the malt be well separated, or clotted together. Formerly, every craft had its mysteries, which were hid from the uninitiated, for whom some wonderful tale was invented that might satisfy their curiosity without adding to their information. Another of those mystical symbols will be seen in the following instructions, which were sent to a lady by an eminent Scotch brewer:

“*Leith, 11th November, 1793.*

“DEAR MADAM,

“* * * * I have sent you 18 lbs. of hops. I generally put in 7 lbs. to the boll* of my best ale, but I think 6 lbs. of these hops should do; and, as good store (yeast) is essentially necessary to the making of strong ale, I have sent you up as much in a small cask as will answer your brewing, the produce of my double ale.

“* * * * * I shall use the freedom of mentioning a few directions, at least, that I follow:—I, in the first place, allow the liquor, or water, in the copper, to come to a boil for ten minutes or so. I then run it off into the mash-tun, and cool it to 190 degrees by the thermometer: or, if you have not one, you may stir it for eight or ten minutes, which brings it near about it. I then put in the malt, and stir it well till all is wet. I then throw a little dry malt, which is left on purpose, on the top of the mash, with a handful of salt, to keep the witches from it, and then cover it up. I allow it then to stand three hours, and then let go the cock of the mash-tun, and run off the wort slowly, to keep it fine, into the wort-

* About 9 lb. per quarter.

stane*. When the first is run off, I sparge it with liquor at 180 degrees; allowing the cock to run all the time till I have as much as I want of quantity. I then pump the worts into the copper, (having put more liquor on the goods for the following, or small beer, at 160 or 165°) and allow them to boil *for an hour*. Having mashed the hops with liquor at the time of sparging the malt, they are put in when putting the worts into the copper. After they are boiled the *above-mentioned time*, I throw them (the worts) into the coolers, and allow them to stand till cool. I then let them into the tun, giving them some store; and, after they are *chipped*†, I add more store by degrees; and, mixing them frequently with a scoop, or cudy‡, I let them stand still till the fermentation is very strong; perhaps three days. I then tun (cleanse) them into casks, filling up twice, or thrice, a day till properly wrought. * * *

"I remain, with esteem, &c.

"W. G."

Mr. G.'s directions, though less minute than those of our Worcestershire friend, show a little more of science, by the introduction of the thermometer. It is surprising, however, considering the comparatively recent period at which he wrote, and his fame as a brewer (for he was the first of his day), that he makes no mention of the saccharometer, in default of which, or something equivalent, no brewing, whether great or small, can be conducted with advantage. Without it, good ale may be made, but the expense, in family brewings, is not calculated: and the proverb is for-

* A stone underback.

† Creamed on the surface.

‡ A *Cudy*, or *Cuddy*, is a small shallow pail, having one of its staves lengthened and shaped so as to form a handle.

gotten, that "what is the private gentleman's boast would be the public brewer's ruin." Further, what with some is reckoned a matter of more consequence, the quality is always uncertain. The malt, it may be, contains a less quantity of fermentable matter, or it does not give out the extract at the heat usually employed. In either case, the same length is drawn; and the discovery is made, a year or two afterwards, in consequence of the obvious weakness, or degeneracy, of the ale. There was a time when instruments were unknown in the brewery; but there was also a time when a *jug*, of indefinite dimensions, was taken as a measure; and a *stone* was selected, by guess-work, from a field, as a representative of weight. Those days, however, are gone by; and, with the degree of knowledge which we now possess, the expectation of being able to brew good malt liquor, without knowing the strength of the worts, seems almost as absurd as to attempt the process, without either weighing the hops or measuring the malt.

Additional information on this subject will be found in the pamphlet which accompanies "*The Brewer's Saccharometer*," an instrument made and adjusted under the direction of the writer of this treatise.

While closing the present treatise, we are well aware that we have left it imperfect. This is partly owing to the narrowness of the limits that have been assigned to it, which has obliged us to abridge many of the illustrations. The treatises on *Wine-making*, and the *Manufacture of Cyder and Perry* (which are, in fact, continuations of *Brewing*) will afford opportunities of remedying, in a great measure, these unavoidable defects.

ERRATA.

Page 16, col. 2, line 4 from the bottom, for *qualities* read *quantities*.
Page 32, note, dele *last* and read 1829.

BELL, Sir Charles

ANIMAL MECHANICS.

THE PERFECTION OF DESIGN IN THE BONES OF THE HEAD, SPINE, AND CHEST, SHOWN BY COMPARISON WITH ARCHITECTURAL AND MECHANICAL CONTRIVANCES.

INTRODUCTION.

To prepare us for perceiving design in the various internal structures of an animal body, we must first of all know, that perfect security against accidents is not consistent with the scheme of nature. A liability to pain and injury only proves how entirely the human body is formed with reference to the mind; since, without the continued call to exertion, which danger and the uncertainty of life infer,—the development of our faculties would be imperfect, and the mind would remain, as it were, uneducated.

The contrivances (as we should say of things of art) for protecting the vital organs are not absolute securities against accidents; but they afford protection in that exact measure or degree which is calculated to resist the shocks and pressure to which we are exposed in the common circumstances of life. A man can walk, run, leap, and swim, because the texture of his frame, the strength and power of his limbs, and the specific gravity of his body are in relation with all around him. But, were the atmosphere lighter, the earth larger, or its attraction more—were he, in short, an inhabitant of another planet, there would be no correspondence between the strength, gravity, and muscular power of his body, and the elements around him, and the balance in the chances of life would be destroyed.

Without such considerations the reader would fall into the mistake, that weakness and liability to fracture imply imperfection in the frame of the body, whereas a deeper contemplation of the subject will convince him of the incomparable perfection both of the plan and of the execution. The body is intended to be subject to derangement and accident, and to become, in the course of

life, more and more fragile, until, by some failure in the frame-work or vital actions, life terminates.

And this leads us to reflect on the best means of informing ourselves of the intention or design shown in this fabric. Can there be any better mode of raising our admiration than by comparing it with things of human invention? It must be allowed, that we shall not find a perfect analogy. If we compare it with the forms of architecture—the house or the bridge are not built for motion, but for solidity and firmness, on the principle of gravitation. The ship rests in equilibrium prepared for passive motion, and the contrivances of the ship-builders are for resisting an external force: whilst in the animal body we perceive securities against the gravitation of the parts, provisions to withstand shocks and injuries from without, at the same time that the framework is also calculated to sustain an internal impulse from the muscular force which moves the bones as levers, or, like a hydraulic-engine, propels the fluids through the body.

We have further to notice that, as in things artificially contrived, lightness and motion are balanced against solidity and weight, it is the same in the animal body. A house is built on a foundation immoveable, and the slightest shift of the ground, followed by the ruin of the house, brings no discredit on the builder; for he proceeds on the certainty of strength from gravitation on a fixed foundation. But a ship is built with reference to motion, to receive an impulse from the wind, and to move through the water. In comparison with the fabric, founded on the fixed and solid ground, it becomes subjected to new influences, and in proportion as it is fitted to move rapidly in a light

breeze, it is exposed to founder in the storm. A log of wood, or a Dutch dogger almost as solid as a log, is comparatively safe in the trough of the sea during a storm—when a bark, slightly built and fitted for lighter breezes, would be shaken to pieces: that is to say, the masts and rigging of a ship (the provisions for its motion) may become the source of weakness, and, perhaps, of destruction; and safety is thus voluntarily sacrificed in part, to obtain another quality for motion.

So in the animal body: sometimes we see the safety of parts provided for by strength calculated for inert resistance; but when made for motion, when light and easily influenced, they become proportionally weak and exposed, unless some other principle be admitted, and a different kind of security substituted for that of weight and solidity: still a certain insecurity arises from this delicacy of structure.

We shall afterwards have occasion to show that there is always a balance between the power of exertion and the capability of resistance in the living body. A horse or a deer receives a shock in alighting from a leap; but still the inert power of resisting that shock bears a relation to the muscular power with which they spring. And so it is in a man: the elasticity of his limbs is always accommodated to his activity; but it is obvious, that in a fall, the shock, which the lower extremities are calculated to resist, may come on the upper extremity, which, from being adapted for extensive and rapid motion, is incapable of sustaining the impulse, and the bones are broken or displaced.

The analogy between the structure of the human body and the works of human contrivance, which we have to bring in illustration of the designs of nature, is, therefore, not perfect: since sometimes the material is different, sometimes the end to be attained is not precisely the same; and, above all, in the animal body a double object is often secured by the structure or framework, which cannot be accomplished by mere human ingenuity, and of which, therefore, we can offer no illustration strictly correct.

However ingenious our contrivances may be, they are not only limited, but they present a sameness which becomes tiresome. Nature, on the contrary, gives us the same objects of interest, or

images of beauty, with such variety, that they lose nothing of their influence and their attraction by repetition.

If the reader has an imperfect notion of design and providence, from a too careless survey of external nature, and the consequent languor of his reflexions, we hope that the mere novelty of the instances we are about to place before him, may carry conviction to his mind; for we are to draw from nature still, but in a field which has been left strangely neglected, though the nearest to us of all, and of all the most fruitful.

Men proceed in a slow course of advancement in architectural, or mechanical, or optical sciences; and when an improvement is made, it is found that there are all along examples of it in the animal body, which ought to have been marked before, and which might have suggested to us the improvement.

It is surprising that this view of the subject has seldom, if ever, been taken seriously, and never pursued. Is the human body formed by an all-perfect Architect, or is it not? And, if the question be answered in the affirmative, does it not approach to something like infatuation, that possessing such perfect models as we have in the anatomy of the body, we yet have been so prone to neglect them?

We undertake to prove, that the foundation of the Eddystone lighthouse, the perfection of human architecture and ingenuity, is not formed on principles so correct, as those which have directed the arrangement of the bones of the foot; That the most perfect pillar or kingpost is not adjusted with the accuracy of the hollow bones which support our weight; That the insertion of a ship's mast into the hull is a clumsy contrivance compared with the connexions of the human spine and pelvis; And that the tendons are composed in a manner superior to the last patent cables of Huddart, or the yet more recently improved chain-cables of Bloxam.

Let us assume that the head is the noblest part; and let us examine the carpentry and architectural contrivances exhibited there.

But, before we give ourselves up to the interest of this subject, it will gratify us to express our conviction, that the perfection of the plan of animal

bodies, the demonstration of contrivance and adaptation, but more than these, the proof of the continual operation of the power which originally created the system, are evinced in the property of life,—in the adjustment of the various sensibilities,—in the fine order of the moving parts of the body,—in the circulation of living blood,—in the continual death of particles, and their removal from the frame,—in the permanence of the individual whilst every material particle of his frame is a thousand times* changed in the progress of his life. But this is altogether a distinct inquiry, and we are deterred from touching upon it, not more from knowing that our readers are not initiated into it, than from the depth and very great difficulty of the subject.

CHAPTER I.

Architecture of the Skull.

It requires no disquisition to prove that the brain is the most essential organ of the animal system, and being so, we may presume that it must be especially protected. We are now to inquire how this main object is attained?

We must first understand that the brain may be hurt, not only by sharp bodies touching and entering it, but by a blow upon the head which shall vibrate through it, without the instrument piercing the skull. Indeed, a blow upon a man's head, by a body which shall cause a vibration through the substance of the brain, may more effectually deprive him of sense and motion than if an axe or a sword penetrated into the substance of the brain itself.

Supposing that a man's ingenuity were to be exercised in contriving a protection to the brain, he must perceive that if the case were soft, it would be too easily pierced; that if it were of a glassy nature, it would be chipped and cracked; that if it were of a substance like metal, it would ring and vibrate, and communicate the concussion to the brain.

Further thoughts might suggest, that whilst the case should be made firm to resist a sharp point, the vibrations of that circular case might be prevented by lining it with a softer material; no bell would vibrate with such an incumbance; the sound would be stopped like the ringing of a glass by the touch of a finger.

If a soldier's head be covered with a steel cap, the blow of a sword which does not penetrate will yet bring him to the ground by the percussion which extends to the brain; therefore, the helmet is lined with leather, and covered with hair; for, although the hair is made an ornament, it is an essential part of the protection: we may see it in the head-piece of the Roman soldier, where all useless ornament being despised as frivolous, was avoided as cumbrous.

We now perceive why the skull consists of two plates of bone, one external, which is fibrous and tough, and one internal, dense to such a degree that the anatomist calls it *tabula vitrea* (the glassy table.)

Nobody can suppose this to be accidental. It has just been stated, that the brain may be injured in two ways: a stone or a hammer may break the skull, and the depressed part of the bone injure the brain; whilst, on the other hand, a mallet struck upon the head will, without penetrating, effectually deprive the brain of its functions, by causing a vibration which runs round the skull and extends to every portion of its contents.

Were the skull, in its perfect or mature state, softer than it is, it would be like the skull of a child; were it harder than we find it is, it would be like that of an old man. In other words, as in the former it would be too easily pierced, so, in the latter, it would vibrate too sharply and produce concussion. The skull of an infant is a single layer of elastic bone; on the approach to manhood it separates into two tables; and in old age it again becomes consolidated. During the active years of man's life the skull is perfect: it then consists of two layers, united by a softer substance; the inner layer is brittle as glass, and calculated to resist anything penetrating; the outer table is tough, to give consistence, and to stifle the vibration which would take place if the whole texture were uniform and like the inner table.

* The old philosophers gave out that the human body was seven times changed during the natural life. Modern discoveries have shown that the hardest material of the frame is changing continually; that is, every instant of time, from birth to death.

The alteration in the substance of the bones, and more particularly in the skull, is marvellously ordered to follow the changes in the mind of the creature, from the heedlessness of childhood to the caution of age, and even the helplessness of superannuation.

The skull is soft and yielding at birth; during childhood it is elastic, and little liable to injury from concussion; and during youth, and up to the period of maturity, the parts which come in contact with the ground, are thicker, whilst the shock is dispersed towards the sutures (the seams or joinings of the pieces), which are still loose. But when, with advancing years, something tells us to give up feats of activity, and falls are less frequent, the bones lose that nature which would render concussion harmless, and at length the timidity of age teaches man that his structure is no longer adapted to active life.

We must understand the necessity of the double layer of the skull, in order to comprehend another very curious contrivance. The sutures are the lines of union of the several bones which form the *cranium**, and surround and protect the brain. These lines of union are called *sutures* (from the Latin word for *sewing*), because they resemble seams. If a workman were to inspect the joining of two of the bones of the cranium, he would admire the minute dove-tailing by which one portion of the bone is inserted into, and surrounded by, the other, whilst that other pushes its processes or jutting out between those of the first in the same manner, and the fibres of the two bones are thus interlaced, as you might interlace your fingers. But when you look to the internal surface, you see nothing of this kind; the bones are here laid simply in contact, and this line by anatomists is called *harmonia*, or harmony: architects use the same term to imply the joining by masonry. Whilst the anatomists are thus curious in names, it is provoking to find them negligent of things more interesting. Having overlooked the reason of the difference in the tables of bone, they are consequently blind to the purpose of this difference of the outward and inward part of a suture.

* *Cranium*, from a Greek word signifying a helmet. The cranium is the division of the skull appropriated to the protection of the brain; it consists of six bones—the *frontal* (or forehead); two *parietal* (walls or side bones); the *occipital* (back of the head); and two *temporal* (or temple) bones.

Suppose a carpenter employed upon his own material, he would join a box with minute and regular indentations by dovetailing, because he knows that the material on which he works, from its softness and toughness, admits of such adjustment of its edges. The processes of the bone shoot into the opposite cavity with an exact resemblance to the foxtail wedge of the carpenter—a kind of tenon and mortice when the pieces are small.

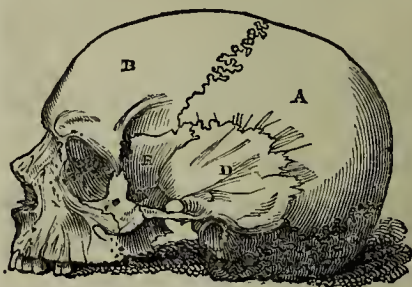
But if a workman in glass or marble were to inclose some precious thing, he would smooth the surfaces and unite them by cement, because, even if he could succeed in indenting the line of union, he knows that his material would chip off on the slightest vibration.

The edges of the marble cylinders which form a column are, for the same reason, not permitted to come in contact; thin plates of lead are interposed to prevent the edges, technically termed *arrises*, from chipping off or splitting.

Now apply this principle to the skull. The outer softer tough table, which is like wood, is indented and dovetailed; the inner glassy table has its edges simply laid in contact. It is mortifying to see a course of bad reasoning obscure this beautiful subject. They say that the bone growing from its centre, and diverging, shoots its fibres betwixt those which come in an opposite direction; thus making one of the most curious provisions of nature a thing of accident. Is it not enough to ask such reasoners, why there is not a suture on the inside as well as on the out?

The junction of the bones of the head generally being thus exact, and like the most finished piece of cabinet work, let us next inquire, whether there be design or contrivance shown in the manner in which each bone is placed upon another.

Fig 1.



- A. The *parietal* bone.
- B. The *frontal* bone.
- C. The *occipital* bone.
- D. The *temporal* bone.
- E. The *sphenoid* bone.

When we look upon the side of the skull thus, the temporal suture betwixt the bones A and D is formed in a peculiar manner; the lower, or temporal, bone laps over the superior, or parietal, bone. This, too, has been misunderstood; that is to say, the plan of the building of the bones of the head has not been considered; and this joining, which is called the squamous* suture, which is a species of scarfing, has been supposed a mere consequence of the pressure of the muscle which moves the jaw.

Dr. Monro says, "the manner how I imagine this sort of suture is formed at these places, is, that by the action of the strong temporal muscles on one side, and by the pressure of the brain on the other, the bones are made so thin that they have not large enough surfaces opposed to each other to stop the extension of their fibres in length, and thus to cause the common serrated appearance of sutures; but the narrow edge of the one bone slides over the other."

The very name of the bones might suggest a better explanation. The *ossa parietalia*† are the two large bones in a regular square, serving as walls to the interior or room of the head, where the brain is lodged.—See A in the foregoing figure.

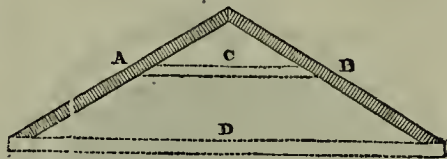
Did the reader ever notice how the walls of a house are assisted when thin and overburdened with a roof?

The *wall plate* is a portion of timber built into the wall, to which a transverse or tie-beam is attached by carpentry.

This *cogging*, as it is termed, keeps the wall in the perpendicular, and prevents any lateral pressure of the roof.‡ We sometimes see a more clumsy contrivance, a clasp, or a round plate of iron, upon the side of a wall; this has a screw going into the ends of a cross-beam, and by embracing a large portion of the brick-work, it holds the wall

from shifting at this point. Or take the instance of a roof supported on inclined rafters, A B:—

Fig. 2.



Were they thus, without further security, placed upon the walls, the weight would tend to spur or press out the walls, which must be strong and heavy to support the roof; therefore, the skeleton of the roof is made into a *truss*, (for so the whole joined carpentry is called.) The upper cross-beam marked by the dotted lines C, is a collar-beam, connecting the rafters of the roof, and stiffening them, and making the weight bear perpendicularly upon the walls. When the transverse beam joins the extremities of the rafters, as indicated by the lower outline D, it is called a *tie-beam*, and is more powerful still in preventing the rafters from pushing out the walls.

Now when a man bears a burden upon his head, the pressure, or horizontal push, comes upon the lower part of the *parietal* bones, and if they had not a tie-beam, they would, in fact, be spurred out, and the bones of the head be crushed down. But the temporal bone D, and still more, the sphenoid bone E, by running across the base of the skull, and having their edges lapping over the lower part of the great walls, or the parietal bones, lock in the walls as if they had iron plates, and answer the purpose of the tie-beam in the roof, or the iron plate in the walls. But the connexion is at the same time so secure, that these bones act equally as a *straining* piece, that is, as a piece of timber, preventing the tendency of the sides of the skull to each other. It may be said, that the skull is not so much like the wall of a house as like the arch of a bridge; let us then consider it in this light.

We have here the two parietal bones, separated and resting against each other, so as to form an arch.

In the centering, which is the wooden frame for supporting a stone arch while building, there are some principles that are applicable to the head.

* From *squama*, the Latin for a *scale*, the thin edges lying over each other like the scales of a fish.

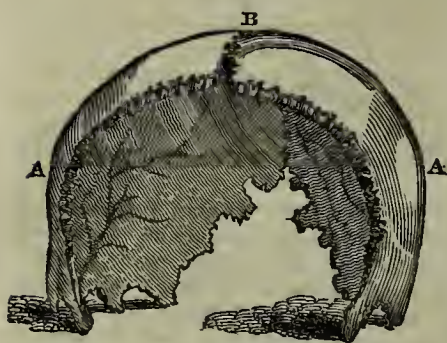
† From the Latin word *paries*, a wall.

‡ In the second Treatise on Heat, the reader will find an account of the manner in which the expansion of iron by heat, and its subsequent contraction on cooling, is used in order to cog great buildings,

We see that the arch formed by the two parietal bones is not a perfect semi-

preventing the arch from being crushed in at this point.

Fig. 3.



The necessity of strengthening certain points is well exhibited in the carpentry of roofs. In this figure it is clear, that the points A A will receive the pressure of the roof, and if the joining of the puncheons* and rafters be not secure, it will sink down in the form of the dotted line. The workmen would apply braces at these angles to strengthen them.

In the arch, and at the corresponding points of the parietal bones, the object is attained by strengthening these points by increase of their convexity and thickness; and where the workman would support the angles by braces, there are ridges of bone, in the calvaria†, or roof of the skull.

If a stone arch fall, it must give way in two places at the same time; the centre cannot sink unless that part of the arch which springs from the pier yields: and in all arches, from the imperfect Roman arch to that built upon modern principles, the aim of the architect is to give security to this point.

In the Roman bridges still entire the arch rises high, with little inclination at the lower part; and in bridges of a more modern date, we see a mass of masonry erected on the pier, sometimes assuming the form of ornament, sometimes of a tower or gateway, but obviously intended at the same time, by the perpendicular load, to resist the horizontal pressure of the arch.

If this be omitted in more modern buildings, it is supplied by a finer art, which gives security to the masonry of the pier (to borrow the terms of anatomy), by its internal structure.

In what is termed Gothic Architecture, we see a flying buttress, springing from the outer wall, carried over the roof of the aisle, and abutting against the wall of the upper part, or *clere-story*.

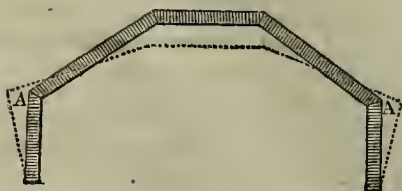
From the upright part of this masonry, a pinnacle is raised, which at first appears to be a mere ornament, but which is necessary, by its perpendicular weight, to counteract the horizontal thrust of the arch.

circle; there is a projection at the centre of each bone, the bone is more convex, and thicker at this part.

The cause assigned for this is, that it is the point from which ossification begins, and where it is, therefore, most perfect. But this is to admit a dangerous principle, that the forms of the bones are matter of chance: and thence we are left without a motive for study, and make no endeavour to comprehend the uses of parts. We find that all the parts which are most exposed to injury are thus strengthened;—the centre of the forehead, the projecting point of the skull behind, and the lateral centres of the parietal and frontal bones. The parts of the head which would strike upon the ground when a man falls, are the strongest, and the projecting arch of the parietal bone is a protection to the weaker temporal bone.

If we compare the skull to the *centering*, where a bridge is to be built over a navigable river, and consequently where the space must be free in the middle, we find that the scientific workmen are careful, by a transverse beam, to protect the points where the principal thrust will be made in carrying up the masonry: this beam does not act as a tie-beam, but as a straining-piece,

Fig. 4.



* The puncheons are the upright lateral pieces; the rafters are the timbers which lie oblique, and join the puncheons at A A.

† From the Latin *calva* or *calvaria*, a helmet.

Fig. 5.



By all this, we see that if the skull is to be considered as an arch, and the parietal bones as forming that arch, they must be secured at the temporal and sphenoid* bones, the points from which they spring.

And, in point of fact, where is it that the skull yields when a man falls, so as to strike the top of his head upon the ground?—in the temples. And yet the joinings are so secure, that the extremity of the bone does not start from its connexions. It must be fractured before it is spurred out, and in that case only does the upper part of the arch yield.

But the best illustration of the form of the head is the dome.

A dome is a vault rising from a circular or elliptical base; and the human skull is, in fact, an elliptical surmounted dome, which latter term means that the dome is higher than the radius of its base. Taking this matter historically, we should presume that the dome was the most difficult piece of architecture, since the first dome erected appears to have been at Rome, in the reign of Augustus—the Pantheon, which

is still entire. The dome of St. Sophia, in Constantinople, built in the time of the Emperor Justinian, fell three times during its erection: and the dome of the Cathedral of Florence stood unfinished 120 years for want of an architect. Yet we may, in one sense, say that every builder who tried it, as well as every labourer employed, had the most perfect model in his own head. It is obvious enough, that the weight of the upper part of the dome must disengage the stones from each other which form the lower circle, and tend to break up their joinings, and consequently to press or thrust outwards the circular wall on which it rests. No walls can support the weight, or rather, the lateral thrust, unless each stone of the dome be soldered to another, or the whole hooped together and girded. The dome of St. Paul's has a very strong double iron chain, linked together, at the bottom of the cone; and several other lesser chains between that and the cupola, which may be seen in the section of St. Paul's engraved by Hooker.

The bones of the head are securely bound together, so that the anatomist finds, when every thing is gone, save the bone itself, and there is neither muscle, ligament, nor membrane of any kind, to connect the bones, they are, still, securely joined, and it requires his art to burst them asunder; and for this purpose he must employ a force which shall produce a uniform pressure from the centre outwards; and all the sutures must receive the pressure at one time and equally, or they will not give way. And now is the time to observe another circumstance, which calls for our admiration. So little of accident is there in the joining of the bones, that the edge of a bone at the suture lies over the adjoining bone at one part and under it at another, which, with the dovetailing of the suture, as before described, holds each bone in its place firmly attached; and it is this which gives security to the dome of the cranium.

If we look at the skull in front, we may consider the orbits of the eye as crypts under the greater building. And these under-arches are groined, that is to say, there are strong arched spines of bone, which give strength sufficient to permit the interstices of the groinings; if I may so term them, to be very thin. Betwixt the eye and the brain, the bone is as thin as parchment; but if the

* In the Greek, *sphenoid*—in the Latin, *cuneiform*—like a wedge, because it is wedged among the other bones of the head; but these processes, called wedges, are more like dovetails, which enter into the irregularities of the bones, and hold them locked.

anterior part of the skull had to rest on this, the foundation would be insufficient. This is the purpose of the strong ridge of bone which runs up like a buttress from the temple to the lateral part of the frontal bone, whilst the arch forming the upper part of the orbit is very strong: and these ridges of bone, when the skull is formed with what we call a due regard to security, give an extension to the forehead*.

In concluding this survey of the architecture of the head, let us suppose it so expanded that we could look upon it from within. In looking up to the vault, we should at once perceive the application of the *groin* in masonry; for the groin is that projection in the vault which results from the intersection of two arches running in different directions. One rib or groin extends from the centre of the frontal bone to the most projecting part of the occipital foramen, or opening on the back of the head; the other rib crosses it from side to side of the occipital bone. The point of intersection of these two groins is the thickest and strongest part of the skull, and it is the most exposed, since it is the part of the head which would strike upon the ground when a man falls backwards.

What is termed the base of the skull is strengthened, if we may so express it, on the same principle: it is like a cylinder groin, where the rib of an arch does not terminate upon a buttress or pilaster, but is continued round in the completion of the circle.

The base of the skull is irregular, and in many places thin and weak, but these arched spines or ribs give it strength to bear those shocks to which it is of course liable at the joining of the skull with the spine.

CHAPTER II.

Mechanism of the Spine.

THE brain-case is thus a perfect whole, secure on all sides, and strengthened where the exposure to injury is the greatest. We shall see, in the column which

sustains it, equal provision for the security of the brain; and, what is most admirable, there is an entirely different principle introduced here; for whereas in the head, the whole aim is firmness in the joinings of the bones, in the spine which supports the head, the object to be attained is mobility or pliancy. In the head, each bone is firmly secured to another; in the spine the bones are not permitted to touch: there is interposed a soft and elastic material, which takes off the jar that would result from the contact of the bones. We shall consider this subject a little more in detail.

The spinal column, as it is called, serves three purposes: it is the great bond of union betwixt all the parts of the skeleton; it forms a tube for the lodgment of the spinal marrow, a part of the nervous system as important to life as the brain itself; and, lastly, it is a column to sustain the head.

We now see the importance of the spine, and we shall next explain how the various offices are provided for.

If the protection of the spinal marrow had been the only object of this structure, it is natural to infer that it would have been a strong and unyielding tube of bone; but, as it must yield to the inflexions of the body, it cannot be constituted in so strict an analogy with the skull. It must, therefore, bend; but it must have no abrupt or considerable bending at one part; for the spinal marrow within would in this way suffer.

By this consideration we perceive why there are twenty-four bones in the spine, each bending a little; each articulated or making a joint with its fellow; all yielding in a slight degree, and, consequently, permitting in the whole spine that flexibility necessary to the motions of the body. It is next to be observed that, whilst the spine by this provision moves in every direction, it gains a property which it belongs more to our present purpose to understand. The bones of the spine are called *vertebræ*; at each interstice between these bones, there is a peculiar gristly substance, which is squeezed out from betwixt the bones, and, therefore, permits them to approach and play a little in the motions of the body. This gristly substance is inclosed in an elastic binding, or membrane of great strength, which passes from the edge or border of one vertebra, to the border of the one next,

* Although they are solid arches connected with the building of the cranium, and bear no relation to the surfaces of the brain, the early craniologists would have persuaded us that their forms corresponded with the surfaces of the brain, and indicate particular capacities or talents,

it. When a weight is upon the body, the soft gristle is pressed out, and the membrane yields: the moment the weight is removed, the membranes recoil by their elasticity, the gristle is pressed into its place, and the bones resume their position.

We can readily understand how great the influence of these twenty-four joinings must be in giving elasticity to the whole column; and how much this must tend to the protection of the brain. Were it not for this interposition of elastic material, every motion of the body would produce a jar to the delicate texture of the brain, and we should suffer almost as much in alighting on our feet, as in falling on our head. It is, as we have already remarked, necessary to interpose thin plates of lead or slate between the different pieces of a column to prevent the edges (technically called arrises) of the cylinders from coming in contact, as they would, in that case, chip or split off.

But there is another very curious provision for the protection of the brain: we mean the curved form of the spine. If a steel spring, perfectly straight, be pressed betwixt the hands from its extremities, it will resist, notwithstanding its elasticity, and when it does give way, it will be with a jerk.

Such would be the effect on the spine if it stood upright, one bone perpendicular to another; for then the weight would bear equally; the spine would yield neither to one side nor to the other; and, consequently, there would be a resistance from the pressure on all sides being balanced. We, therefore, see the great advantage resulting from the human spine being in the form of an italic *f*. It is prepared to yield in the direction of its curves; the pressure is of necessity more upon one side of the column than on the other; and its elasticity is immediately in operation without a jerk. It yields, recoils, and so forms the most perfect spring; admirably calculated to carry the head without jar, or injury of any kind.

The most unhappy illustration of all this is the condition of old age. The tables of the skull are then consolidated, and the spine is rigid: if an old man should fall with his head upon the carpet, the blow, which would be of no consequence to the elastic frame of a child, may to him prove fatal; and the rigidity of the spine makes every step

which he takes vibrate to the interior of the head, and jar on the brain.

We have hinted at a comparison betwixt the attachment of the spine to the pelvis and the insertion of the mast of a ship into the hull. The mast goes directly through the decks without touching them, and the heel of the mast goes into the step, which is formed of large solid pieces of oak timber laid across the keelson. The keelson is an inner keel resting upon the floor-timbers of the ship and directly over the proper keel. These are contrivances for enlarging the base on which the mast rests as a column: for as, in proportion to the height and weight of a column, its base must be enlarged, or it would sink into the earth; so, if the mast were to bear upon a point, it would break through the bottom of the ship.

The mast is supported upright by the shrouds and stays. The shrouds secure it against the lateral or rolling motion, and the stays and backstays against the pitching of the ship. These form what is termed the standing rigging.

The mast does not bear upon the deck or on the beams of the ship; indeed there is a space covered with canvas betwixt the deck and the mast.

We often hear of a new ship going to sea to stretch her rigging; that is, to permit the shrouds and stays to be stretched by the motion of the ship, after which they are again braced tight: for if she were overtaken by a storm before this operation, and when the stays and shrouds were relaxed, the mast would lean against the upper deck, by which it would be sprung or carried away. Indeed, the greater proportion of masts that are lost are lost in this manner. There are no boats which keep the sea in such storms as those which navigate the gulf of Finland. Their masts are not attached at all to the hull of the ship, but simply rest upon the step.

Although the spine has not a strict resemblance to the mast, the contrivances of the ship-builder, however different from the provisions of nature, shows what object is to be attained; and when we are thus made aware of what is necessary to the security of a column on a moveable base, we are prepared to appreciate the superior provisions of nature for giving security to the human spine.

The human spine rests on what is

called the *pelvis*, or basin;—a circle of bones, of which the haunches are the extreme lateral parts; and the sacrum (which is as the keystone of the arch) may be felt at the lower part of the back. To this central bone of the arch of the pelvis the spine is connected; and, taking the similitude of the mast, the sacrum is as the *step* on which the base of the pillar, like the heel of the mast, is socketed or morticed. The spine is tied to the lateral parts of the pelvis by powerful ligaments, which may be compared to the shrouds. They secure the lower part of the spine against the shock of lateral motion or rolling; but, instead of the stays to limit the play of the spine forwards and backwards in pitching, or to adjust the rake of the mast, there is a very beautiful contrivance in the lower part of the column.

The spine forms here a semicircle which has this effect; that, whether by the exertion of the lower extremities, the spine is to be carried forward upon the pelvis, or whether the body stops suddenly in running, the jar which would necessarily take place at the lower part of the spine A, if it stood upright like a mast, is distributed over several of the bones of the spine, 1, 2, 3, 4, and, therefore, the chance of injury at any particular part is diminished.

Fig. 6.



For example, the sacrum, or centre bone of the pelvis, being carried forward, as when one is about to run, the

force is communicated to the lowest bone of the spine. But, then, the surfaces of these bones stand with a very slight degree of obliquity to the line of motion; the shock communicated from the lower to the second bone of the vertebræ is still in a direction very nearly perpendicular to its surface of contact. The same takes place in the communication of force from the second to the third, and from the third to the fourth; so that before the shock of the horizontal motion acts upon the perpendicular spine, it is distributed over four bones of that column, instead of the whole force being concentrated upon the joining of any two, as at A.

If the column stood upright, as indicated at C D, it would be jarred at the lowest point of contact with its base. But by forming a semicircle A B, the motion which is in the direction E F, would produce a jar on the very lowest part of the column, and which is distributed over a considerable portion of the column A B; and in point of fact, this part of the spine never gives way. Indeed, we should be inclined to offer this model to the consideration of nautical men, as fruitful in hints for improving naval architecture.

Every one who has seen a ship pitching in a heavy sea, must have asked himself why the masts are not upright, or rather, why the foremast stands upright, whilst the main and mizen masts stand oblique to the deck, or, as the phrase is, rake aft or towards the stern of the ship.

The main and mizen masts incline backwards, because the strain is greatest in the forward pitch of the vessel; for the mast having received an impulse forwards, it is suddenly checked as the head of the ship rises; but the mast being set with an inclination backwards, the motion falls more in the perpendicular line from the head to the heel. This advantage is lost in the upright position of the foremast, but it is sacrificed to a superior advantage gained in working the ship; the sails upon this mast act more powerfully in swaying the vessel round, and the perpendicular position causes the ship to tack or stay better; but the perpendicular position, as we have seen, causes the strain in pitching to come at right angles to the mast, and is, therefore, more apt to spring it.

These considerations give an interest

to the fact, that the human spine, from its utmost convexity near its base, inclines backwards.

CHAPTER III.

Of the Chest.

IN extending the parallel which we proposed between the structure of the body and the works of human art, it signifies very little to what part we turn; for the happy adaptation of means to the end will everywhere challenge our admiration, in exact proportion to our success in comprehending the provisions which Supreme Wisdom has made. We turn now to a short view of the bones of the chest.

The thorax, or chest, is composed of bones and cartilages, so disposed as to sustain and protect the most vital parts, the heart and lungs, and to turn and twist with perfect facility in every motion of the body; and to be in incessant motion in the act of respiration, without a moment's interval during a whole life. In anatomical description, the thorax is formed of the vertebral column, or spine, on the back part, the ribs on either side, and the breastbone, or sternum, on the fore part. But the thing most to be admired is the manner in which these bones are united, and especially the manner in which the ribs are joined to the breastbone, by the interposition of cartilages, or gristle, of a substance softer than bone, and more elastic and yielding. By this quality they are fitted for protecting the chest against the effects of violence, and even for sustaining life after the muscular power of respiration has become too feeble to continue without this support.

If the ribs were complete circles, formed of bone, and extending from the spine to the breastbone, life would be endangered by any accidental fracture; and even the rubs and jolts to which the human frame is continually exposed, would be too much for their delicate and brittle texture. But these evils are avoided by the interposition of the elastic cartilage. On their forepart the ribs are eked out, and joined to the breastbone by means of cartilages, of a form corresponding to that of the ribs, being, as it were, a completion of the arch of the rib, by a substance more

adapted to yield in every shock or motion of the body. The elasticity of this portion subdues those shocks which would occasion the breaking of the ribs. We lean forward, or to one side, and the ribs accommodate themselves, not by a change of form in the bones, but by the bending or elasticity of the cartilages. A severe blow upon the ribs does not break them, because their extremities recoil and yield to the violence. It is only in youth, however, when the human frame is in perfection, that this pliancy and elasticity have full effect. When old age approaches, the cartilages of the ribs become bony. They attach themselves firmly to the breastbone, and the extremities of the ribs are fixed, as if the whole arch were formed of bone unyielding and inelastic. Then every violent blow upon the side is attended with fracture of the rib, an accident seldom occurring in childhood, or in youth.

But there is a purpose still more important to be accomplished by means of the elastic structure of the ribs, as partly formed of cartilage. This is in the action of breathing, or respiration; especially in the more highly-raised respiration which is necessary in great exertions of bodily strength, and in violent exercise. There are two acts of breathing—*expiration*, or the sending forth of the breath; and *inspiration*, or the drawing in of the breath. When the chest is at rest, it is neither in the state of expiration nor in that of inspiration; it is in an intermediate condition between these two acts. And the muscular effort by which either inspiration or expiration is produced, is an act in opposition to the elastic property of the ribs. The property of the ribs is to preserve the breast in the intermediate state between expiration and inspiration. The muscles of respiration are excited alternately, to dilate or to contract the cavity of the chest, and, in doing so, to raise or to depress the ribs. Hence it is, that both in inspiration and in expiration the elasticity of the ribs is called into play; and, were it within our province, it would be easy to show, that the dead power of the cartilages of the ribs preserve life by respiration, after the vital muscular power would, without such assistance, be too weak to continue life.

It will at once be understood, from what has now been explained, how, in

age, violent exercise or exertion is under restraint, in so far as it depends on respiration. The elasticity of the cartilages is gone, the circle of the ribs is now unyielding, and will not allow that high breathing, that sudden and great dilating and contracting of the cavity of the chest, which is required for circulating the blood through the lungs, and relieving the heart amidst the more tumultuous flowing of the blood which exercise and exertion produce.

CHAPTER IV.

Structure of the Bones and Joints of the Extremities.

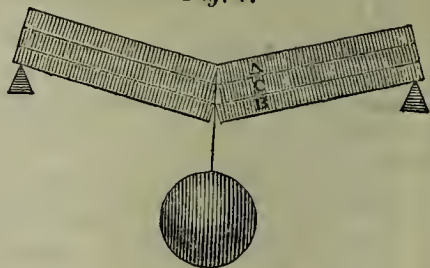
THAT the bones, which form the interior of animal bodies, should have the most perfect shape, combining strength and lightness, ought not to surprize us, when we find this in the lowest vegetable production.

In the sixteenth century, an unfortunate man who taught medicine, philosophy, and theology, was accused of atheistical opinions, and condemned to have his tongue cut out, and suffer death. When brought from his cell before the inquisition, he was asked if he believed in God. Picking up a straw which had stuck to his garments, "If," said he, "there was nothing else in nature to teach me the existence of a Deity, even this straw would be sufficient!" A reed, or a quill, or a bone, may be taken to prove that in Nature's works strength is given with the least possible expense of materials. The long bones of animals are, for the most part, hollow cylinders, filled up with the lightest substance, marrow; and in birds the object is attained by means (if we may be permitted to say so) still more artificial. Every one must have observed, that the breast-bone of a fowl extends along the whole body, and that the body is very large compared with the weight: this is for the purpose of rendering the creature specifically lighter and more buoyant in the air; and that it may have a surface for the attachment of muscles, equal to the exertion of raising it on the wing. This combination of lightness with increase of volume, is gained by air-cells extending through the body, and communicating by tubes between the lungs and cavities of the bones. By these

means, the bones, although large and strong to withstand the operation of powerful muscles upon them, are much lighter than those of quadrupeds.

The long bones of the human body, being hollow tubes, are called cylindrical, though they are not accurately so, the reason of which we shall presently explain; and we shall, at the same time, show that their irregularities are not accidental, as some have imagined. But let us first demonstrate the advantage which, in the structure of the bones, is derived from the cylindrical form, or a form approaching to that of the cylinder. If a piece of timber supported on two points, thus—

Fig. 7.

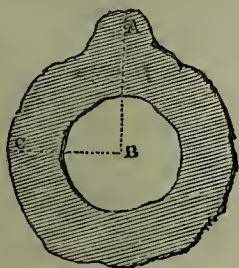


bear a weight upon it, it sustains this weight by different qualities in its different parts. For example, divide it into three equal parts (A, B, C,): the upper part A supports the weight by its solidity and resistance to compression; the lowest part B, on the other hand, resists by its toughness, or adhesive quality. Betwixt the portions acting in so different a manner there is an intermediate neutral, or central part C, that may be taken away without materially weakening the beam, which shows that a hollow cylinder is the form of strength. The Writer lately observed a good demonstration of this:—a large tree was blown down, and lay upon the ground; to the windward, the broken part gaped; it had been torn asunder like the snapping of a rope: to the leeward side of the tree, the fibres of the stem were crushed into one another and splintered; whilst the central part remained entire. This, we presume, must be always the case, more or less; and here we take the opportunity of noticing why the arch is the form of strength. If this transverse piece of timber were in the form of an arch, and supported at the extremities, then its whole thickness, its centre, as well as the upper

and lower parts, would support weight by resisting compression. But the demonstration may be carried much farther to show the form of strength in the bone. If the part of the cylinder which bears the pressure be made more dense, the power of resistance will be much increased; whereas, if a ligamentous covering be added on the other side, it will strengthen the part which resists extension: and we observe a provision of this kind in the tough ligaments which run along the vertebræ of the back.

When we see the bone cut across, we are forced to acknowledge that it is formed on the principle of the cylinder; that is, that the material is removed from the centre, and accumulated on the circumference, thus—

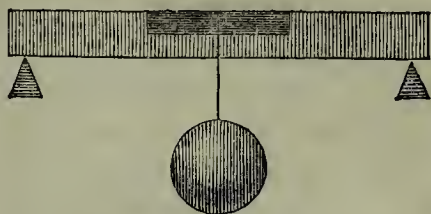
Fig. 8.



We find a spine, or ridge running along the bone, which, when divided by the saw in a transverse direction, exhibits an irregularity, as at A.

The section of this spine shows a surface as dense as ivory, which is, therefore, much more capable of resisting compression than the other part of the cylinder, which is common bone. This declares what the spine is, and the anatomists must be wrong who imagine that the bone is moulded by the action of the muscle, and that the spine is a mere ridge, arising by accident among the muscles. It is, on the contrary, a strengthening of the bone in the direction on which the weight bears. If we resume the experiment with the piece of timber, we shall learn why the spine is harder than the rest of the bone. If a portion of the upper part of the timber be cut away, and a harder wood inserted in its place, the beam will acquire a new power of resisting fracture, because, as we have stated, this part of the wood does not yield but by being crushed, and the in-

Fig. 9.



section of the harder portion of wood increases this property of resistance. With this fact before us we may return to the examination of the spine of bone. We see that it is calculated to resist pressure, first, because it is farther removed from the centre of the cylinder; and, secondly, because it is denser, to resist compression, than the other part of the circumference of the bone*.

This explanation of the use of a spine upon a bone gives a new interest to osteology†. The anatomist ought to deduce from the form of the spine the motions of the limb; the forces bearing upon the bone, and the nature and the common place of fracture: while, to the general enquirer an agreeable process of reasoning is introduced in that department, which is altogether without interest when the “irregularities” of the bone are spoken of, as if they were the accidental consequences of the pressure of the flesh upon it.

Although treating of the purely mechanic principle, it is, perhaps, not far removed from our proper object to remark, that a person of feeble texture and indolent habits has the bone smooth, thin, and light; but that Nature, solicitous for our safety, in a manner which we could not anticipate, combines with the powerful muscular frame a dense and perfect texture of bone, where every spine and tubercle is completely developed. And thus the inert and mechanical provisions of the bone always bear relation to the muscular power of the limb, and exercise is as necessary to the perfect constitution of a bone as it is to the perfection of the muscular power. Jockies speak correctly enough, when they use the term “*blood and*

* As the line A B extends farther from the centre than B C, on the principle of a lever, the resistance to transverse fracture will be greater in the direction A B than B C.

† *Osteology*, from the Greek words, signifying discourse on bone, being the demonstration of the forms and connexion of the different bones.

bone," as distinguishing the breed or genealogy of horses; for blood is an allowable term for the race, and bone is so far significant, that the bone of a running horse is remarkably compact compared with the bone of a draught horse. The reader can easily understand, that the span in the gallop must give a shock in proportion to its length; and, as in man, so in the horse, the greater the muscular power the denser and stronger is the bone. The bone not being as a mere pillar, intended to bear a perpendicular weight, we ought not to expect uniformity in its shape. Each bone, according to its place, bears up against the varying forces that are applied to it. Consider two men wrestling together, and then think how various the property of resistances must be: here they are pulling, and the bones are like ropes; or again, they are writhing and twisting, and the bones bear a force like the axle-tree between two wheels; or they are like a pillar under a great weight; or they are acting as a lever.

To withstand these different shocks, a bone consists of three parts, the *earth* of bone (sub-phosphate of lime); *fibres* to give it toughness; and *cartilage* to give it elasticity. These ingredients are not uniformly mixed up in all bones; but some bones are hard, from the prevalence of the earth of bone; some more fibrous, to resist a pull upon them; and some more elastic, to resist the shocks in walking, leaping, &c. But to return to the forms:—Whilst the centre of the long bones is, as we have stated, cylindrical, their extremities are expanded, and assume various shapes. The expansion of the head of the bone is to give a greater, and consequently a more secure surface for the joint, and its form regulates the direction in which the joint is to move. A jockey, putting his hand on the knee of a colt, and finding it broad and flat, augurs the perfection of the full-grown horse. To admit of this enlargement and difference of form, a change in the internal structure of the bone is necessary, and the hollow of the tube is filled up with *cancelli*, or lattice-work. These *cancelli* of the bone are minute and delicate-like wires, which form lattice-work, extending in all directions through the interior of the bone, and which, were it elastic, would be like a sponge.—This more uniform texture of the

bone permits the outer shell to be very thin, so that whilst the centre of the long bones are cylinders, their extremities are of a uniform cancellated structure. But it is pertinent to our purpose to notice, that this minute lattice-work, or the *cancelli* which constitute the interior structure of bone, have still reference to the forces acting on the bone; if any one doubts this, let him make a section of the upper and lower end of the thigh-bone, and let him inquire what is the meaning of the difference in the *lie* of these minute bony fibres, in the two extremities? He will find that the head of the thigh bone stands obliquely off from the shaft, and that the whole weight bears on what is termed the *inner trochanter*; and to that point, as to a buttress, all these delicate fibres converge, or point from the head and neck of the bone, which may be rudely represented in this way.

Fig. 10.



The head of the thigh-bone, to show the direction of the *cancelli*, converging to the line of gravity.

We may here notice an opinion that has been entertained, in regard to the size of animals. It is believed that the material of bone is not capable of supporting a creature larger than the elephant, or the *mastodon*, which is the name of an extinct animal of great size, the osseous remains of which are still found. This opinion is countenanced by observing that their bones are very clumsy, that their spines are of great thickness, and that their hollow cylinders are almost filled up with bone.

It may be illustrated in this manner:—A soft stone projecting from a wall may make a stile, strong enough to bear a person's weight; but if it were neces-

sary to double its length, the thickness must be more than doubled, or a freestone substituted; and were it necessary to make this freestone project twice as far from the wall, even if doubled in thickness, it would not be strong enough to bear a proportioned increase of weight: granite must be placed in its stead; and even the granite would not be capable of sustaining four times the weight which the soft stone bore in the first instance. In the same way the stones which form an arch of a large span must be of the hardest granite, or their own weight would crush them. The same principle is applicable to the bones of animals. The material of bone is too soft to admit an indefinite increase of weight; and it is another illustration of what was before stated, that there is a relation established through all nature, and that the very animals which move upon the surface of the earth are proportioned to its *magnitude*, and the gravitation to its centre. Archdeacon Paley has with great propriety taken the instance of the form of the ends of bones, as proving design in the mechanism of a joint. But there is something so highly interesting in the conformation of the whole skeleton of an animal, and the adaptation of any one part to all the other parts, that we must not let our readers remain ignorant of the facts, or of the important conclusions drawn from them.

What we have to state has been the result of the studies of many naturalists; but although they have laboured, as it were, in their own department of comparative anatomy, they have failed to seize upon it with the privilege of genius, and to handle it in the masterly manner of Cuvier.

Suppose a man ignorant of anatomy to pick up a bone in an unexplored country, he learns nothing, except that some animal has lived and died there; but the anatomist can, by that single bone, estimate, not merely the size of the animal, as well as if he saw the print of its foot, but the form and joints of the skeleton, the structure of its jaws and teeth, the nature of its food, and its internal economy. This, to one ignorant of the subject, must appear wonderful, but it is after this manner that the anatomist proceeds: let us suppose that he has taken up that portion of bone in the limb of the quadruped which corresponds to the human wrist;

and that he finds that the form of the bone does not admit of free motion in various directions, like the paw of the carnivorous creature. It is obvious, by the structure of the part, that the limb must have been merely for supporting the animal, and for progression, and not for seizing prey. This leads him to the fact that there were no bones resembling those of the hand and fingers, or those of the claws of the tiger; for the motions which that conformation of bones permits in the paw, would be useless, without the rotation of the wrist—he concludes that these bones were formed in one mass, like the cannon bone, pastern-bone, and coffin-bones of the horse's foot.*

The motion limited to flexion and extension of the foot of a hoofed animal implies the absence of a collar bone and a restrained motion in the shoulder joint; and thus the naturalist, from the specimen in his hand, has got a perfect notion of all the bones of the anterior extremity! The motions of the extremities imply a condition of the spine which unites them. Each bone of the spine will have that form which permits the bounding of the stag, or the galloping of the horse, but it will not have that form of joining which admits the turning or writhing of the spine, as in the leopard or the tiger.

And now he comes to the head:—the teeth of a carnivorous animal, he says, would be useless to rend prey, unless there were claws to hold it, and a mobility of the extremities like the hand, to grasp it. He considers, therefore, that the teeth must have been for bruising herbs, and the back teeth for grinding. The socketing of these teeth in the jaw gives a peculiar form to these bones, and the muscles which move them are also peculiar; in short, he forms a conception of the shape of the skull. From this point he may set out anew, for by the form of the teeth, he ascertains the nature of the stomach, the length of the intestines, and all the peculiarities which mark a vegetable feeder.

Thus the whole parts of the animal system are so connected with one another, that from one single bone or frag-

* For these are solid bones, where it is difficult to recognise any resemblance to the carpus, metacarpus and bones of the fingers; and yet comparative anatomy proves that these moveable bones are of the same class with those in the solid hoof of the *bellux* of Linnæus.

ment of bone, be it of the jaw, or of the spine, or of the extremity, a really accurate conception of the shape, motions, and habits of the animal, may be formed.

It will readily be understood that the same process of reasoning will ascertain, from a small portion of a skeleton, the existence of a carnivorous animal, or of a fowl, or of a bat, or of a lizard, or of a fish; and what a conviction is here brought home to us, of the extent of that plan which adapts the members of every creature to its proper office, and yet exhibits a system extending through the whole range of animated beings, whose motions are conducted by the operation of muscles and bones!

After all, this is but a part of the wonders disclosed through the knowledge of a thing so despised as a fragment of bone. It carries us into another science; since the knowledge of the skeleton not only teaches us the classification of creatures, now alive, but affords proofs of the former existence of animated beings which are not now to be found on the surface of the earth. We are thus led to an unexpected conclusion from such premises: not merely the existence of an individual animal, or race of animals; but even the changes which the globe itself has undergone in times before all existing records, and before the creation of human beings to inhabit the earth, are opened to our contemplation.

Of Standing.

This may appear to some a very simple inquiry, and yet it is very ignorant to suppose that it is so. The subject has been introduced in this fashion:—"Observe these men engaged in raising a statue to its pedestal with the contrivances of pulleys and levers, and how they have placed it on the pedestal and are soldering it to keep it steady, lest the wind should blow it down. This statue has the fair and perfect proportions of the human body; to all outward appearance it ought to stand."

In the following passage, we have the same idea thrown out in a manner which we are apt to call *French*. Were a man cast on a desert shore, and should there find a beautiful statue of marble, he would naturally exclaim,—“Without

doubt, there have been inhabitants here: I recognise the hand of a famous sculptor: I admire the delicacy with which he has proportioned all the members of the body to give them beauty, grace, and majesty, to indicate the motion and expression of life.” But it may be asked, what would such a man think if his companion were to say,—“Not at all, no sculptor made this statue; it is formed, to be sure, in the best taste, and according to the rules of art, but it is formed by chance: amongst the many fragments of marble, there has been one thus formed of itself. The rain and the winds have detached it from the mountain, and a storm has placed it upright on the pedestal. The pedestal, too, was prepared of itself in this lonely place. True, it is like the Apollo, or the Venus, or the Hercules. You might believe that the figure lived and thought; that it was prepared to move and speak; but it owes nothing to art; blind chance has placed it there.”*

The first passage suggests the conviction that the power of standing proceeds not from any symmetry, as in a pillar, or from gravitation alone. It, in fact, proceeds from an internal provision, by which a man is capable of estimating, with great precision, the inclination of his body, and correcting the bias by the adjustment of the muscles. In the second passage, it is meant to be shown, that the outward proportion of the form bears a relation to the internal structure; that grace and expression are not superficial qualities, and that only the Divine Architect could form such a combination of animated machinery.

We shall consider how the human body is prepared by mechanical contrivances to stand upright, and by what fine sense of the gravitation of the body the muscles are excited to stiffen the otherwise loose joints, and to poise the body on its base.

Of the Foot.

Let us take the arrangement of the bones of the foot, according to the demonstration of the anatomists.

They are divided into the *tarsus*, which is composed of seven bones, reaching from the heel to the middle of the foot. The *metatarsus*, which con-

* *Démonstration de l'Existence de Dieu, par Fénelon.*

sists of five long bones laid parallel to each other, and extending from the *tarsus* to the roots of the toes. The bones of the toes are called *phalanges*, from being in the form of a *phalanx*.

There are in all thirty-six bones in the foot; and the first question that naturally arises, is, why should there be so many bones? The answer is, in order that there may be so many joints; for the structure of a joint not only permits motion, but bestows elasticity.

A joint then consists of the union of two bones, of such a form as to permit the necessary motion: but they are not in contact: each articulating surface is covered with cartilage, to prevent the jar which would result from the contact of the bones. This cartilage is elastic, and the celebrated Dr. Hunter discovered that the elasticity was in consequence of a number of filaments closely compacted, and extending from the surface of the bone, so that each filament is perpendicular to the pressure made upon it. The surface of the articulating cartilage is perfectly smooth, and is lubricated by a fluid called *synovia*, signifying a mucilage, a viscous or thick liquor. This is vulgarly called *joint oil*, but it has no property of oil, although it is better calculated than any oil to lubricate the interior of the joint.

When inflammation comes upon a joint, this fluid is not supplied, and the joint is stiff, and the surfaces creak upon one another like a hinge without oil. A delicate membrane extends from bone to bone, confining this lubricating fluid, and forming the boundary of what is termed the cavity of the joint, although, in fact, there is no unoccupied space. External to this capsule* of the joint, there are strong ligaments going from point to point of the bones, and so ordered as to bind them together without preventing their proper motions. From this description of a single joint, we can easily conceive what a spring or elasticity is given to the foot, where thirty-six bones are jointed together.

An elegant author has this very natural remark on the joints:—"In considering the joints, there is nothing, perhaps, which ought to move our gratitude more than the reflection, *how well they wear*. A limb shall swing upon

its hinge, or play in its socket many hundred times in an hour, for sixty years together, without diminution of its agility, which is a long time for anything to last, for anything so much worked and exercised as the joints are. This durability I should attribute, in part, to the provision which is made for the preventing of wear and tear: first, by the polish of cartilaginous surfaces; secondly, by the healing lubrication of the mucilage; and, in part, to that astonishing property of animal constitutions, assimilation, by which, in every portion of the body, let it consist of what it will, substance is restored and waste repaired."—*Paley*.

If the ingenious author's mind had been professionally called to contemplate this subject, he would have found another explanation. There is no resemblance betwixt the provisions against the wear and tear of machinery and those for the preservation of a living part. As the structure of the parts is originally perfected by the action of the vessels, the function or operation of the part is made the stimulus to those vessels. The cuticle on the hands wears away like a glove; but the pressure stimulates the living surface to force successive layers of skin under that which is wearing, or, as the Anatomists call it, *disquamating*; by which they mean, that the cuticle does not change at once, but comes off in *squamæ*, or scales. The teeth are subject to pressure in chewing or masticating, and they would, by this action, have been driven deeper in the jaw, and rendered useless, had there not been a provision against this mechanical effect. This provision is a disposition to grow, or rather to shoot out of their sockets; and this disposition to project, balances the pressure which they sustain; and when one tooth is lost, its opposite rises, and is in danger of being lost also, for want of that very opposition.

The most obvious proof of contrivance is the junction of the foot to the bones of the leg at the ankle joint. The two bones of the leg, called the *tibia* and the *fibula*, receive the great articulating bone of the foot (the *astragalus*) betwixt them. And the extremities of these bones of the leg project so as to form the outer and inner ankle. Now, when we step forward, and whilst the foot is raised, it rolls easily upon the ends of these bones, so that the toe

* From *capsula*, a little case, or box.

may be directed according to the inequalities of the ground we are to tread upon ; but when the foot is planted, and the body is carried forward perpendicularly over the foot, the joint of the leg and foot becomes fixed, and we have a steady base to rest upon. We next observe, that, in walking, the heel first touches the ground. If the bones of the leg were perpendicular over the part which first touches the ground, we should come down with a sudden jolt, instead of which we descend in a semi-circle, the centre of which is the point of the heel.

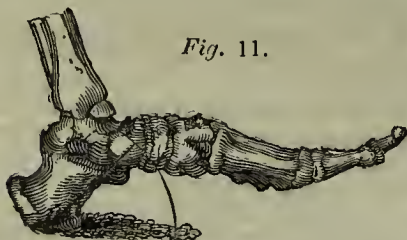


Fig. 11.

And when the toes have come to the ground we are far from losing the advantages of the structure of the foot, since we stand upon an elastic arch, the hinder extremity of which is the heel, and the anterior the balls of the toes. A finely formed foot should be high in the instep. The walk of opera dancers is neither natural nor beautiful ; but the surprising exercises which they perform give to the joints of the foot a freedom of motion almost like that of the hand. We have seen the dancers, in their morning exercises, stand for twenty minutes on the extremities of their toes, after which the effort is to bend the inner ankle down to the floor, in preparation for the Bolero step. By such unnatural postures and exercises the foot is made unfit for walking, as may be observed in any of the retired dancers and old *figurantes*. By standing so much upon the toes, the human foot is converted to something more resembling that of a quadruped, where the heel never reaches the ground, and where the paw is nothing more than the phalanges of the toes.

This arch of the foot, from the heel to the toe, has the astragalus (A) resembling the keystone of an arch ; but, instead of being fixed, as in masonry, it plays freely betwixt two bones, and from these two bones, B and C, a strong

Fig. 12.



elastic ligament is extended, on which the bone (A) rests, sinking or rising as the weight of the body bears upon it, or is taken off, and this it is enabled to do by the action of the ligament which runs under it.

This is the same elastic ligament which runs extensively along the back of the horse's hind leg and foot, and gives the fine spring to it, but which is sometimes ruptured by the exertion of the animal in a leap, producing irrecoverable lameness.

Having understood that the arch of the foot is perfect from the heel to the toe, we have next to observe, that there is an arch from side to side ; for when a transverse section is made of the bones of the foot, the exposed surface presents a perfect arch of wedges, regularly formed like the stones of an arch in masonry. If we look down upon the bones of the foot, we shall see that they form a complete circle horizontally, leaving a space in their centre. These bones thus form three different arches —forward ; across ; and horizontally : they are wedged together, and bound by ligaments, and this is what we alluded to when we said that the foundations of the Eddystone were not laid on a better principle ; but our admiration is more excited in observing, that the bones of the foot are not only wedged together, like the courses of stone for resistance, but that solidity is combined with elasticity and lightness.

Notwithstanding the mobility of the foot in some positions, yet when the weight of the body bears directly over it, it becomes immovable, and the bones of the leg must be fractured before the foot yields.

We shall proceed to explain how the knee-joint and hip-joint, independently of the exertion of muscles, become firm in the standing position, and when at rest : but, before we enter upon this, let us understand the much talked-of demonstration of Borelli, who explained the manner in which a bird sits upon a branch when asleep. The weight of

the creature, and the consequent flexion of the limbs drawing the tendons of the talons, so as to make them grasp the branch without muscular effort.

Fig. 13.



The muscle A passing over the joint at B, and then proceeding to the back of the leg, and behind the joint at C, and so descending behind the foot at D, it extends to the talons; and the weight of the bird, bending the joint B and C, produces the effect of muscular effort, and makes the claws cling.

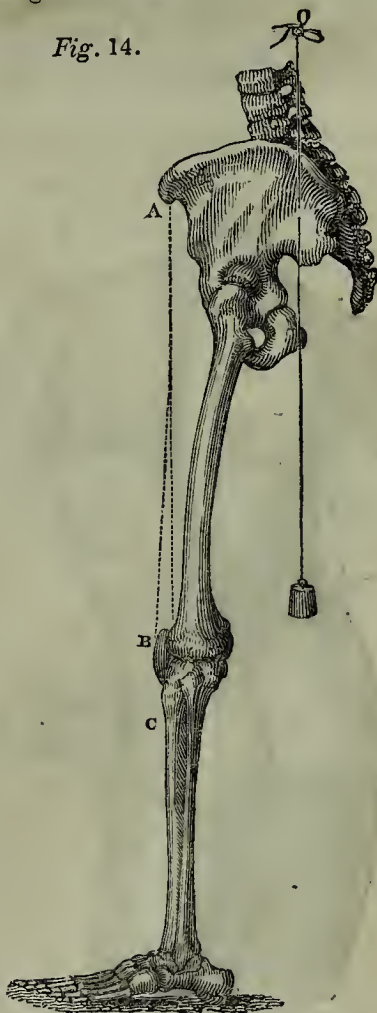
But why should the anatomist have recourse to this piece of comparative anatomy, when he has so fine an example in the human body? And one which is much more interesting, as, in fact, it is the foundation of reasoning upon the diseases and accidents of the limb. If this beautiful arrangement in the healthy and perfect structure of a man's limb be not attended to, it would be easy to prove that many important circumstances, in regard to disease and accidents, must remain obscure.

The posture of a soldier under arms, when his heels are close together, and his knees straight, is a condition of painful restraint. Observe, then, the change in the body and limbs, when he is ordered to stand at ease; the firelock falls against his relaxed arms, the right knee is thrown out, and the tension of the ankle joint of the same leg is relieved, whilst he loses an inch and a half of his height, and sinks down upon his left hip. This command

to "stand at ease," has a higher authority than the general orders. It is a natural relaxation of all the muscles; which are, consequently, relieved from a painful state of exertion: and the weight of the body bears so upon the lower extremity, as to support the joints independently of muscular effort. The advantage of this will be understood, when we consider that all muscular effort is made at the expense of a living power, which, if excessive, will exhaust and weary a man, whilst the position of rest which we are describing is without effort, and therefore gives perfect relief. And it is this which makes boys and girls, who are out of health and languid, lounge too much in the position of relief, from whence comes permanent distortion.

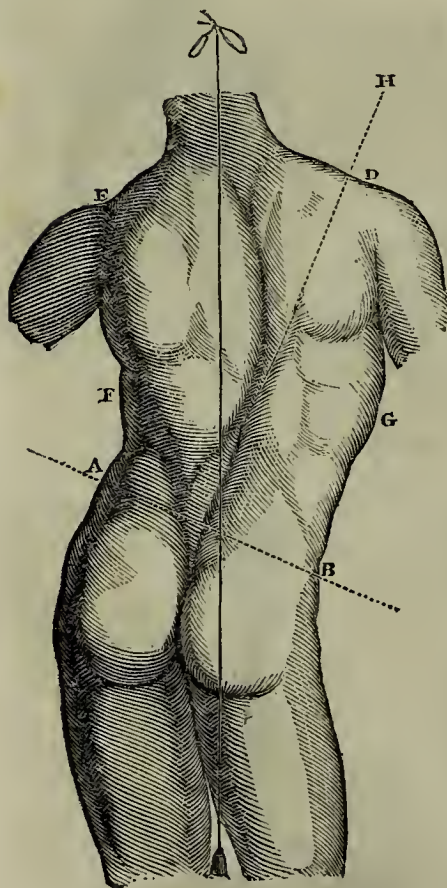
This figure represents the bones of the leg.

Fig. 14.



The plumb-line shows the direction of the gravitation of the body falling behind the head of the thighbone. Now, if it be understood that the motions of the trunk are performed on the centre of the head of the thighbone; it must follow that the weight of the body in the direction of the plumb-line must raise the corner of the haunch-bone, at A. From this corner of the bone, a broad and strong band runs down to the knee-pan, B, in the direction of the dotted line. The powerful muscles which extend the leg are attached to the knee-pan, and through the ligament at C, operate on the bones of the leg, stretching them, and preventing the flexion of the joint; but, in the absence of the activity of these muscles, the band reaching from A to B, drawn, as we have said, by the weight of the body, is equivalent to the exertion of the muscles, braces the knee-joint, and extends the leg; and we have before

Fig. 15.



seen that the extension of the leg fixes the ankle-joint. Thus the limb is made a firm pillar under the weight of the body, without muscular effort.

When the human figure is left to its natural attitudes, we see a variety and contrast in the position of the trunk and limbs.

This position of the body resting on the lower extremities throws the trunk into an elegant line, and places the limbs in beautiful contrast, as we see in all the best specimens of sculpture. *See fig. 15.*

Now that we have understood that the lower extremity becomes in some positions a firm pillar, it is the more necessary to observe the particular form of the head of the thigh bone, (*fig. 16.*)

Fig. 16.



It is here seen that the head of the bone A stands off from the shaft by the whole length of the neck of the bone B; the effect of this is, that as the powerful muscles are attached to the knobs of bone C D, they turn the thigh-bone round in walking with much greater power than if the head of the bone were on a line with the shaft. They, in fact, acquire a lever power, by the distance of D from A, as, during the action of these muscles, the limb is stiff, the rolling of the thigh directs the toe outwards in walking.

When the weight of the body is perpendicularly over the ball of the great toe, the whole body is twisted round on that point as on a pivot. This rolling

of the body on the ball of the toe, and consequent turning out of the toes in stepping forward, is necessary to the freedom and elasticity of the motion. The form of all the bones of the leg, and the direction of all the muscles of the thigh and leg, combine to this effect. So far is it from being true, as painters affect to say, that the turning out of the toes is the result of the lessons of the dancing-master.

A certain squareness in the position of the feet is consistent with strength, as we see in the statues of the Hercules, &c.; but the lightness of a Mercury is indicated by the direction of the toes outwards. In women, there would be a defect from the breadth of the pelvis, and a rolling and an awkward gait would be the consequence; but in them the foot is more turned out, and a light, elastic step balances the defect arising from the form of the pelvis. Any one may be convinced of this by observing people who walk awkwardly, especially if they walk unequally. Look at their feet, and you will see that one foot goes straight forward, whilst the other is turned outwards, and that when they come upon the straight foot, they come down awkwardly, and have no spring from it.

There is another curious circumstance in the form of the thighbone, showing how it is calculated for strength as well as freedom of motion. To understand it, we must first look to the *dishing* of a wheel—the dishing is the oblique position of the spokes from the nave to the felly, giving the wheel a slightly conical form. When a cart is in the middle of a road, the load bears equally upon both wheels, and both wheels stand with their spokes oblique to the line of gravitation.

If the cart is moving on the side of a barrel-shaped road, or if one wheel falls into a rut, the whole weight comes upon one wheel: but the spokes of that wheel, which were oblique to the load when it supported only one half of the weight, are now perpendicular under the pressure, and are capable of sustaining the whole. If roads were made perfectly level, and had no holes in them, the wheels of carts might be made without dishing; but if a cart is calculated for a country road, let the wheelwright consider what equivalent he has to give for that very pretty result pro-

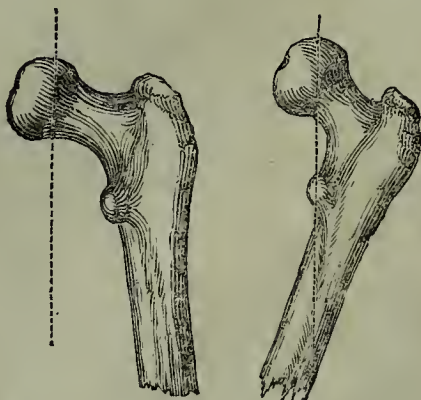
Fig. 17.



ceeding from the obliquity of the spokes, or *dishing* of the wheel.

When we return to consider the human thighbone, we see that the same principle holds; that is to say, that whilst a man stands on both his legs, the necks of the thigh bones are oblique to the line of gravitation of the body; but when one foot is raised, the whole body then being balanced on one foot, a change takes place in the position of the thighbone, and the obliquity of that bone is diminished; or, in other words, now that it has the whole weight to sustain, it is perpendicular under it, and has therefore acquired greater strength. See Fig. 18.

Fig. 18.



CHAPTER V

Of the Cordage of the Tendons.

WHERE nature has provided a perfect system of columns, and levers, and pulleys, we may anticipate that the cords by which the force of the muscles is concentrated on the moveable bones, must be constructed with as curious a provision for their offices. In this surmise we shall not be disappointed.

To understand what is necessary to the strength of a rope or cable, we must learn what has been the object of the improvements and patents in this manufacture. The first process in rope-making, is hatchelling the hemp; that is, combing out the short fibres, and placing the long ones parallel to one another. The second is, spinning the hemp into yarns. And here the principle must be attended to, which goes through the whole process in forming a cable; which is that the fibres of the hemp shall bear an equal strain: and the difficulty may be easily conceived, since the twisting must derange the parallel position of the fibres. Each fibre, as it is twisted, ties the other fibres together, so as to form a continued line, and it bears at the same time, a certain portion of the strain, and so each fibre alternately. The third step of the process is making the yarns. Warping the yarns, is stretching them to a certain length; and for the same reason, that so much attention has been paid to the arrangement of the fibres for the yarns, the same care is taken in the management of the yarns for the strands. The fourth step of the process is to form the strands into ropes. The difficulty of the art has been to make them bear alike, especially in great cables, and this has been the object of patent machinery. The *hardening*, by twisting, is also an essential part of the process of rope-making; for without this, it would be little better than extended parallel fibres of hemp. In this twisting, first of the yarns, and then of the strands, those which are on the outer surface must be more stretched than those near the centre; consequently, when there is a strain upon the rope, the outer fibres will break first, and the others in succession. It is to avoid this, that each yarn and each strand, as it is twisted or hardened, shall be itself revolving, so

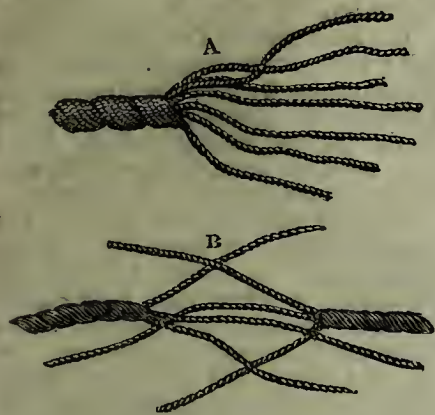
that when drawn into the cable, the whole component parts may, as nearly as possible, resist the strain in an equal degree; but the process is not perfect, and this we must conclude from observing how different the construction of a tendon is from that of a rope. A tendon consists of a strong cord, apparently fibrous; but which, by the art of the anatomist, may be separated into lesser cords, and these, by maceration, can be shown to consist of cellular membrane, the common tissue that gives firmness to all the textures of the animal body. The peculiarity here results merely from its remarkable condensation. But the cords of which the larger tendon consists, do not lie parallel to each other, nor are they simply twisted like the strands of a rope; they are, on the contrary, plaited or interwoven together.

If the strong tendon of the heel, or Achilles tendon, be taken as an example, on first inspection, it appears to consist of parallel fibres, but by maceration, these fibres are found to be a web of twisted cellular texture. If you take your handkerchief, and, slightly twisting it, draw it out like a rope, it will seem to consist of parallel cords; such is, in fact, so far the structure of a tendon. But, as we have stated, there is something more admirable than this, for the tendon consists of subdivisions, which are like the strands of a rope; but instead of being twisted simply as by the process of hardening, they are plaited or interwoven in a way that could not be imitated in cordage by the turning of a wheel. Here then is the difference,—by the twisting of a rope, the strands cannot resist the strain equally, whilst we see that this is provided for in the tendon by the regular interweaving of the yarn, if we may so express it, so that every fibre deviates from the parallel line in the same degree, and, consequently, receives the same strain when the tendon is pulled. If we seek for examples illustrative of this structure of the tendons, we must turn to the subject of ship-rigging, and see there how the seaman contrives, by undoing the strands and yarns of a rope, and twisting them anew, to make his splicing stronger than the original cordage. A sailor opens the ends of two ropes thus:*

* A, Strands and Yarns opened.

B, Ends opened and laid for splicing, in a manner exactly like the interlacing of the tendon.

Fig. 19.



and places the strand of one opposite and between the strand of another, and so interlaces them. And this explains why a hawser-rope, a sort of small cable, is spun of *three* strands; for as they are necessary for many operations in the rigging of a ship, they must be formed in a way that admits of being cut and spliced, for the separation of three strands, at least, is necessary for knotting, splicing, whipping, mailing, &c., which are a few of the many curious contrivances for joining the ends of ropes, and for strengthening them by filling up the interstices to preserve them from being cut or frayed. As these methods of splicing and plaiting in the subdivisions of the rope make an intertexture stronger than the original rope, it is an additional demonstration, if any were wanted, to show the perfection of the cordage of an animal machine, since the tendons are so interwoven; and until the yarns of one strand be separated and interwoven with the yarns of another strand, and this done with regular exchange, the most approved patent ropes must be inferior to the corresponding part of the animal machinery.

A piece of cord of a new patent has been shown to us, which is said to be many times stronger than any other cord of the same diameter. It is so far upon the principle here stated, that the strands are plaited instead of being twisted; but the tendon has still its superiority, for the lesser yarns of each strand in it are interwoven with those of other strands. It, however, gratifies us to see, that the principle we draw from the animal body is here confirmed. It may be asked, do not the tendons of

the human body sometimes break? They do; but in circumstances which only add to the interest of the subject. By the exercise of the tendons, (and their exercise is the act of being pulled upon by the muscles, or having a strain made on them,) they become firmer and stronger; but in the failure of muscular activity, they become less capable of resisting the tug made upon them, and if, after a long confinement, a man has some powerful excitement to muscular exertion, then the tendon breaks. An old gentleman, whose habits have been long staid and sedentary, and who is very guarded in his walk, is upon an annual festival tempted to join the young people in a dance; then he breaks his tendo Achillis. Or a sick person, long confined to bed, is, on rising, subject to a rupture or hernia, because the tendinous expansions guarding against protrusion of the internal parts, have become weak from disuse.

Such circumstances remind us that we are speaking of a living body, and that, in estimating the properties of the machinery, we ought not to forget the influence of life, and that the natural exercise of the parts, whether they be active or passive, is the stimulus to the circulation through them, and to their growth and perfection.

CHAPTER VI.

Of the Muscles of Elasticity—Muscularity.

THERE are two powers of contraction in the animal frame—elasticity, which is common to living and dead matter, and the muscular power, which is a property of the living fibre.

The muscles are the only organs which properly have the power of contraction, for elasticity is never exerted but in consequence of some other power bending or stretching the elastic body. In the muscles, on the contrary, motion originates; there being no connexion, on mechanical principles, betwixt the exciting cause and the power brought into action.

The real power is in the muscles, while the safeguard against the excess of that power is in the elasticity of the parts. This is obvious in the limbs and general texture of the frame; but it is most perfectly exhibited in the organs

of circulation. If the action of the heart impelled the blood against parts of solid texture, they would quickly yield. When, by accident, this does take place, even the solid bone is very soon destroyed. But the coats of the artery which receive the rush of blood from the heart, although thin, are limber and elastic; and by this elasticity or yielding they take off or subdue the shock of the heart's action, while no force is lost; for as the elastic artery has yielded to the sudden impulse of the heart, it contracts by elasticity in the interval of the heart's pulsation; and the blood continues to be propelled onward in the course of the circulation, without interval, though regularly accelerated by the pulse of the heart.

If a steam-engine were used to force water along the water-pipes, without the intervention of some elastic body, the water would not flow continuously, but in jerks, and, therefore, a reservoir is constructed containing air, into which the water is forced, against the elasticity of the air. Thus, each stroke of the piston is not perceptibly communicated to the conduit-pipe, because the intervals are supplied by the push of the compressed air. The office of the reservoir containing air is performed in the animal body by the elasticity of the coats of the arteries, by which means the blood which flows interruptedly into the arteries has a continuous and uninterrupted flow in the veins beyond them.

A muscle is fibrous, that is, it consists of minute threads bundled together, the extremities of which are connected with the tendons which have been described. Innumerable fibres are thus joined together to form one muscle, and every muscle is a distinct organ. Of these distinct muscles for the motions of the body there are not less than 436 in the human frame, independent of those which perform the internal vital motions. The contractile power, which is in the living muscular fibre, presents appearances which, though familiar, are really the most surprising of all the properties of life. Many attempts have been made to explain this property, sometimes by chemical experiment, sometimes on mechanical principles, but always in a manner repugnant to common sense. We must be satisfied with saying, that it is an endowment, the cause of which it would be

as vain to investigate as to resume the search into the cause of gravitation.

The ignorance of the cause of muscular contraction does not prevent us from studying the laws which regulate it, and under this head are included subjects of the highest interest; which, however, we must leave, to pursue the mechanical arrangement of the muscles.

Since we have seen that there are 436 distinct muscles in the body, it is due to our readers to explain how they are associated to effect that combination which is necessary to the motion of the limbs and to our perfect enjoyment. In the first place, the million of fibres, which constitute a single muscle, are connected by a tissue of nerves, which produce a union or sympathy amongst them, so that one impulse causes a simultaneous effort of all the fibres attached to the same tendon. When we have understood that the muscles are distinct organs of motion, we perceive that they must be classed and associated in order that many shall combine in one act; and that others, their opponents, shall be put in a state to relax, and offer no opposition to those which are active. These relations can only be established through *nerves*, which are the organs of communication with the brain, or sensorium. The nerves convey the will to the muscles, and at the same time they class and arrange them so as to make them consent to the motions of the body and limbs.

On first looking to the manner in which the muscles are fixed into the bones, and the course of their tendons, we observe everywhere the appearance of a sacrifice of mechanical power, the tendon being inserted into the bone in such a manner as to lose the advantage of the lever. This appears to be an imperfection, until we learn that there is an accumulation of vital power in the muscle in order to attain velocity of movement in the member, (*fig. 20.*)

The muscle D, which bends the forearm, is inserted into the radius E, so near the fulcrum, or centre of motion in the elbow joint, and so oblique that it must raise the hand and fore-arm with disadvantage. But, correctly speaking, the power of the muscle is not sacrificed, since it gains more than an equivalent in the rapid and lively motions of the hand and fingers, and since these rapid motions are necessary to us in a thousand familiar actions;

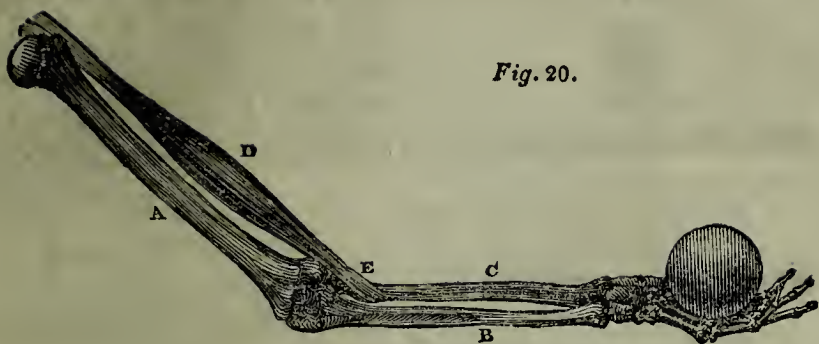


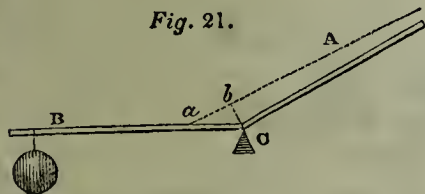
Fig. 20.

and to attain this, the Creator has given sufficient vital power to the muscles to admit of the sacrifice of the mechanical or lever power, and so to provide for every degree and variety of motion which may answer to the capacities of the mind.

If we represent the bones and muscles of the fore-arm by this diagram, we shall see that power is lost by the inclination of the tendon to the lever, into which it is inserted. It represents the lever of the third kind, where the moving power operates on a point nearer the fulcrum than the weight to be moved.

Here A represents the muscle, B the lever, and C the fulcrum. The power of the muscle is not represented by the distance of its insertion *a*, from the

Fig. 21.



fulcrum C. The line which truly represents the lever must pass from the centre of motion, perpendicularly to the line of the tendon, *viz.*, C, *b*. Here, again, by the direction of the tendon, as well as by its actual attachment to the bone, power is lost and velocity gained.

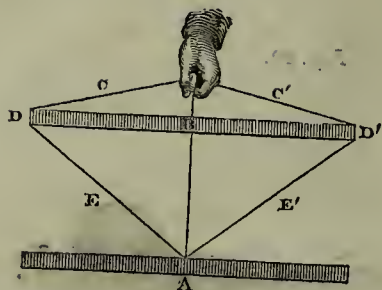
We may compare the muscular power to the weight which impels a machine. In studying machinery, it is manifest that weight and velocity are equivalent. The handle of the winch in a crane is a lever, and the space through which it moves, in comparison with the slow motion of the weight, is the measure of

its power. If the weight, raised by the crane, be permitted to go down, the wheels revolve, and the handle moves with the velocity of a cannon-ball, and will be as destructive if it hit the workman. The weight here is the power, but it operates with so much disadvantage, that the hand upon the handle of the winch can stop it: but give it way, let the accelerated motion take place, and the hand would be shattered which touched it. Just so the fly-wheel, moving at first slowly, and an impediment to the working of a machine, at length acquires momentum, so as to concentrate the power of the machine, and enable it to cut bars of iron with a stroke.

The principle holds in the animal machinery. The elbow is bent with a certain loss of mechanical power; but by that very means, when the loss is supplied by the living muscular power, the hand descends through a greater space, moves quicker, with a velocity which enables us to strike or to cut. Without this acquired velocity, we could not drive a nail: the mere muscular power would be insufficient for many actions quite necessary to our existence.

Let us take some examples to show what objects are attained through the oblique direction of the fibres of the muscle, and we shall see that here, as well as by the mode of attachment of the entire muscle, velocity is attained by the sacrifice of power. Suppose that these two pieces of wood (*fig. 22.*) to be drawn together by means of a cord, but that the hand which pulls, although possessing abundant strength, wants room to recede more than what is equal to one third of the space betwixt the pieces of wood; it is quite clear, that if the hand were to draw direct on the

Fig. 22.

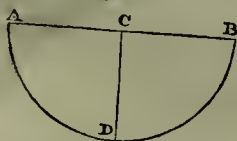


cord A, B, the point A would be brought towards B, through one third only of the intervening space, and the end would not be accomplished. But if the cord were put over the ends of the upper piece, C, D, E, and, consequently, directed obliquely to their attachment at A, on drawing the hand back a very little, but with more force, the lower piece of wood would be suddenly drawn up to the higher piece, and the object attained. Or we may put it in this form:—If a muscle be in the direction of its tendon, the motion of the extremity of the tendon will be the same with that of the muscle itself: but if the attachment of the muscle to the tendon be oblique, it will draw the tendon through a greater space; and if the direction of the muscle devi-

ate so far from the line of the tendon as to be perpendicular to it, it will then be in a condition to draw the tendon through the greatest space with the least contraction of its own length.

Thus, if A, B be a tendon, and C, D a muscle; by the contraction of C to D,

Fig. 23.

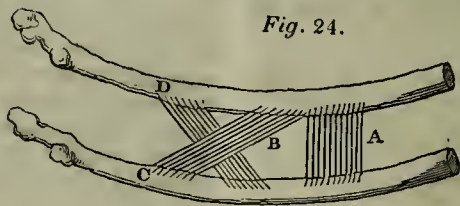


the extremities of the tendon A, B will be brought together, through a space double the contraction of the muscle. It is the adjustment, on the same principle, which gives the arrow so quick an impulse from the spring of the bow, the extremities of the bow drawing obliquely on the string.

To free breathing, it is necessary that the ribs shall approach each other, and this is performed by certain *intercostal* muscles, (or muscles playing between the ribs,) and now we can answer the question, why are the fibres of these muscles oblique?

Let us suppose this figure to represent two ribs with thin intervening muscles. If the fibres of the muscle were

Fig. 24.

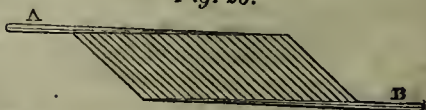


in the direction A, across, and perpendicular to the ribs; and if they were to contract one-third of their length, they would not close the intervening space—they would not accomplish the purpose. But being oblique, as at B, although they contract no more than one-third of their length, they will bring the ribs C, D together. By this obliquity of the intercostal muscles, they are enabled to expand the chest in inspiration, in a manner which could not be otherwise accomplished.

In the greater number of muscles the same principle directs the arrangement of the fibres; they exchange power for velocity of movement, by their obliqui-

ty. They do not go direct from origin to insertion, but obliquely, thus, from tendon to tendon:—

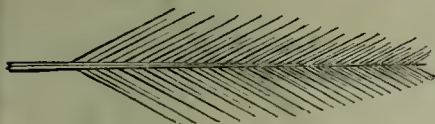
Fig. 25.



Supposing the point A to be the fixed point, these fibres draw the point B with less force, but through a larger space, or more quickly than if they took their course in direct lines; and by this arrangement of the fibres the freedom and extent of motion in our limbs are secured.

But the muscles must be strengthened by additional courses of fibres, because they are oblique; since by their obliquity they lose something of their force of action: and therefore it is, we must presume, that we find them in a double row, making what is termed the *penniform muscle*, thus,—

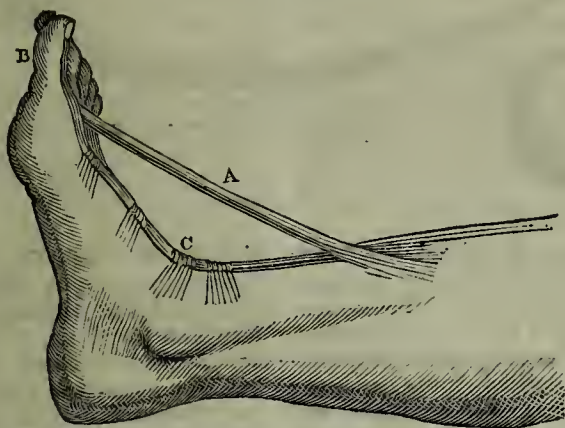
Fig. 26.



and sometimes the texture of the muscle is still further compounded by the intermixture of tendons, which permit additional series of fibres; and all this for the obvious purpose of accumulating power, which may be exchanged for velocity of movement.

We may perceive the same effect to result from the course of the tendons, and their confinement in sheaths, strengthened by cross-straps of ligament. If the tendon, A, (*fig. 27*) took the shortest course to its termination at B, it would draw up the toe with greater force; but then the toe would lose its velocity of movement. By taking the direction

Fig. 27.



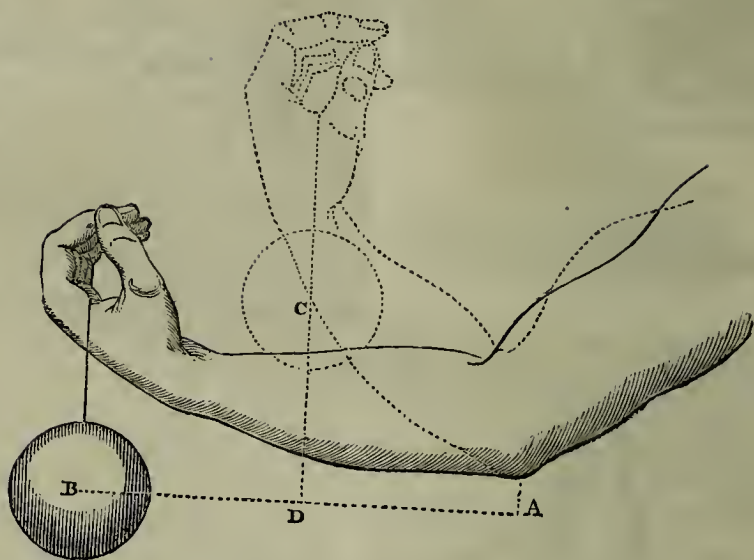
C, close to the joints, the velocity of motion is secured, and by this arrangement the toes possess their spring, and the fingers their lively movements. We may take this opportunity of noticing how the mechanical opposition is diminished as the living muscular power is exhausted. For example, in lifting a weight, the length of the lever of resistance will be from the centre of the elbow joint, A, (*fig. 28*) to the centre of the weight, B. As the muscles of the arm contract, they lose something of their power; but in a greater proportion is the mechanical resistance diminished, for when the weight is raised to C A D, it becomes the measure of the lever of resistance.

A more admirable thing is witnessed by the anatomist—we mean the manner in which the lever, rising or falling, is carried beyond the sphere of action of one class of muscles, and enters the sphere of activity of others. And this adaptation of the organs of motion is

finely adjusted to the mechanical resistance which may arise from the form or motion of the bones. In short, whether we contemplate the million of fibres which constitute one muscle, or the many muscles which combine to the movement of the limb, nothing is more surprising and admirable than the adjustment of their power so as to balance mechanical resistance, arising from the change of position of the levers.

In the animal body, there is a perfect relation preserved betwixt the parts of the same organ. The muscular fibres forming what is termed the belly of the muscle, and the tendon through which the muscle pulls, are two parts of one organ; and the condition of the tendon indicates the state of the muscle. Thus jockies discover the qualities of a horse by its sinews or tendons. The most approved form in the leg of the hunter, or hackney, is that in which three convexities can be distinguished,—the bone; the prominence of

Fig. 23.



the elastic ligament behind the bone; and behind that the flexor tendons, large, round, and strong. Strong tendons are provided for strong muscles, and the size of these indicate the muscular strength. Such muscles, being powerful flexors, cause high and round action, and such horses are safe to ride; their feet are generally preserved good, owing to the pressure they sustain from their high action. But this excellence in a horse will not make him a favourite at Newmarket. The circular motion cannot be the swiftest; a blood-horse carries his foot near the ground. The speed of a horse depends on the strength of his loins and hind quarter; and what is required in the fore-legs is strength of the extensor tendons, so that the feet may be well thrown out before, for if these tendons be not strong, the joints will be unable to sustain the weight of his body, when powerfully thrown forward, by the exertion of his hind-quarters, and he will be apt to come with his nose to the ground.

The whole apparatus of bones and joints being thus originally constituted by Nature in accurate relation to the muscular powers, we have next to observe, that this apparatus is preserved perfect by exercise. The tendons, the

sheaths in which they run, the cross ligaments by which they are restrained, and the *bursæ mucosæ** which are interposed to diminish friction, can be seen in perfection only when the animal machinery has been kept in full activity. In inflammation, and pain, and necessary restraint, they become weak; and even confinement, and want of exercise, without disease, will produce imperfections. Exercise unfolds fully the muscular system, producing a full bold outline of the limbs, at the same time that the joints are knit, small, and clean. In the loins, thighs, and legs of a dancer we see the muscular system fully developed; and when we turn our attention to his puny and disproportioned arms, we acknowledge the cause—that, in the one instance, exercise has produced perfection, and that, in the other, the want of it has occasioned deformity. Look to the legs of a poor Irishman travelling to the harvest with bare feet: the thickness and roundness of the calf show that the foot and toes are free to permit the exercise of the muscles

* These *bursæ mucosæ* (mucous purses) are sacs containing a lubricating fluid. They are interposed wherever there is much pressure or friction, and answer all the purposes of friction-wheels in machinery.

of the leg. Look, again, to the leg of our English peasant, whose foot and ankle are tightly laced in a shoe with a wooden sole, and you will perceive, from the manner in which he lifts his legs, that the play of the ankle, foot, and toes are lost, as much as if he went on stilts, and, therefore, are his legs small and shapeless.

And this brings us naturally to a subject of some interest at present: we mean the new fashion of exercising our youth in a manner which is to supersede dancing, fencing, boxing, rowing, and cricket, and the natural impulse of youth to activity.

By this fashion of training to what are termed *gymnastics*, children at school are to be urged to feats of strength and activity, not restrained by parental authority, nor left to their own sense of pleasurable exertion. They are made to climb, to throw their limbs over a bar, to press their foot close to their hip, their knees close to their stomach; to hang by the arms and raise the body, —to hang by the feet and knees,—to struggle against each other, by placing the soles of their feet in opposition, and to pull with their hands. No doubt, if such exercises be persevered in, the muscular powers will be strongly developed. But the first question to be considered is the safety of this practice. We have seen a professor of gymnastics, by such training, acquire great strength and prominence of muscles; but by this unnatural increase of muscular power, through the exercises he recommended, he became ruptured on both sides. The same accident has happened to boys too suddenly put on these efforts.

It is very necessary to observe, that when the muscular power is thus, we may say, preternaturally increased, whether in the instance of a race-horse, an opera-dancer, or a pupil of the Calisthenic school, it is not merely necessary to put them on their exercises gradually in each successive lesson, but each day's exertion must be preceded by a wearisome preparation. In the great schools, like that at Stockholm, the master makes the boys walk in a circle; then run, at first gently; and so he gradually brings them into heat, and the textures of their frame are composed to that state of elasticity and equal resistance, as well as to vital energy, which is necessary for the safe display

of the greater feats of strength and activity. This caution in the public exercises is the very demonstration of the dangers of the system. The boys will not be always under this severe control, and yet it is important to their safety.

We may learn how necessary it is to bring the animal system gradually into action from the effects of very moderate exercise on a horse just out of the dealer's hands. The purchaser thinks he may safely drive him ten miles, not aware that the horse has not moved a mile in a week, and the consequence is, inflammation and congestion in his lungs. The regulation in the army has been made on a knowledge of these facts. When young horses are brought from the dealer they are ordered to be walked an hour a-day the first week, two hours a-day the second week, three hours a-day in the third week. They are to be fatigued by walking, but they must not be sweated in their exercise. Horses for the turf, under three years old, in training for the Derby, are brought very slowly to their exercise, beginning with the lounge; then a very light weight is put upon them, and that gradually increased. Indeed, nothing can better show the effects of exercise in perfecting the muscular action than the consequence of the loss of one day's training. It will bring the favourite to the bottom of the list, and that without any suspicion of lameness, but from a knowledge of the fact, that even such a slight irregularity in his training will have a sensible effect on his speed. Shall the possibility of pecuniary loss excite the jockey to more care for his horse than we, in our rational and humane attention to the education of our youth, pay to their health and safety?

In reflecting on these many proofs of design in the animal body, it must excite our surprise that anatomy is so little cultivated by men of science. We crowd to see a piece of machinery or a new engine, but neglect to raise the covering which would display in the body the most striking proofs of design, surpassing all art in simplicity and effectiveness, and without any thing useless or superfluous.

A more important deduction from the view of the animal structure is, that our conceptions of the perfection and beauty in the design of nature, are exactly in proportion to the extent of our capacity. We are familiar with the mechanical powers, and we recognise the principles in the structure of the animal machine; and in proportion as we understand the principles of hydrostatics and hydraulics, are able to discern the most beautiful adaptation of them in the vessels of an animal body. But when, to our further progress in anatomy, it is necessary that we should study a matter so difficult as the theory of life, imperfect principles or wrong conceptions distort and obscure the appearances: false and presumptuous theories are formed, or we are thrown back in disappointment into scepticism, as if chance only could produce that, of which we do not comprehend the perfect arrangement. But studies better directed and prosecuted in a better spirit prove that the human body, though deprived of what gave it sense and motion, is still a plan drawn in perfect wisdom.

A man possessed of that humility which is akin to true knowledge, may be depressed by too extensive a survey of the frame of nature. The stupendous changes which the geologist surveys—the incomprehensible magnitude of the heavenly bodies moving in infinite space, bring down his thoughts to a painful sense of his own littleness: “to him the earth with men upon it, will not seem much other than an ant-hill, where some ants carry corn, and some carry their young, and some go empty, and all to and fro a little heap of dust.”*

He is afraid to think himself an object of Divine care; but when he regards the structure of his own body, he learns to consider space and magnitude as nothing to a Creator. He finds that the living being, which he was about to condemn, in comparison with the great system of the universe, exists by the continuance of a power, no less admirable than that which rules the heavenly bodies; he sees that there is a revolution, a circle of motions no less wonderful in his own frame, in the microcosm of man's body, than in the plane-

tary system; that there is not a globule of blood which circulates, but possesses attraction as incomprehensible and wonderful as that which retains the planets in their orbits.

The economy of the animal body, as the economy of the universe, is sufficiently known to us to compel us to acknowledge an Almighty Power in the creation. What would be the consequence of a further insight—whether it would conduce to our peace or happiness—whether it would assist us in our duties, or divert us from the performance of them, is very uncertain.

CHAPTER VII.

Books.

Ray, “On the Wisdom of God manifested in the Works of the Creation,” has several chapters on the animal economy.

Archdeacon Paley has composed a work of high interest, by taking the common anatomical demonstrations, and presenting them in an elegant and popular form. His work is entitled *Natural Theology*; or, *Evidences of the Existence and Attributes of the Deity*, collected from the *Appearances of Nature*.

The celebrated Fenelon has, with the same pious object, composed a small duodecimo, in which he draws his arguments from the structure of animal bodies.

Wollaston, in the “*Religion of Nature delineated*,” has the same train of reflection to prove that there can be no such thing as chance operating in and about what we see or feel; and he says, with great propriety, “How may a man qualify himself so as to be able to judge of the religions professed in the world; to settle his own opinions in disputable matters; and then to enjoy tranquillity of mind, neither disturbing others, nor being disturbed at what passes among them?”

Derham, in sixteen sermons, preached in 1711, at the lecture founded by Mr. Boyle, treats at length of the structure of our organs. These are also published, separately, under the title of *Physico-Theology*; and they naturally suggest to learned divines, the expediency of sometimes expounding to their hearers the evidences of design appa-

* Bacon.

rent in the universe, as a sure means of enlightening their understandings, elevating their views, and awakening their piety.

This cultivation of the mind, by exercising it upon the study of proper objects, is a man's first duty to himself. Without it, he can have no steady opinion on points of the nearest concern.

He is wrought upon by circumstances which ought not to sway the mind of a sensible man ; at one time depressed to the depths of despondency, and, at another, exalted into unreasonable enthusiasm. Without such cultivation, were a man to live a hundred years, he is at last like one cut off in infancy.

ANIMAL MECHANICS,

OR,

PROOFS OF DESIGN IN THE ANIMAL FRAME.

PART II.

SHOWING THE APPLICATION OF THE LIVING FORCES

AMONGST the least informed people, and in remote villages, there are old saws and rules regarding health, sickness and wounds, which might be thought to come from mere experience; but they are, on the contrary, for the most part, the remains of forgotten theories and opinions, laid down by the learned of former days. Portions of knowledge, it would appear, confined at first to a select part of society, are, in the progress of time, diffused generally, and may be recognised in the aphorisms of the poor. These are traced to their source only by the curious few, who like to read old books, and to observe how that which is originally right, becomes, through prejudice and ignorance, distorted and fantastical.

If a very little exact knowledge of the structure of our own frames were more generally diffused, charity would be advanced, empirics could hardly maintain their influence, and medical men might have a farther motive to desire professional eminence.

Men suppose that the knowledge of their own bodies must be a science locked up from them, because of the language in which it is conveyed; or they take away their thoughts from it, as from the contemplation of danger, unwilling to survey the slight ties by which they hold their lives. They are like persons for the first time at sea, who shudder to calculate how many circumstances must concur to speed the frail vessel on its voyage, and how little is between them and the deep. It is then a mean and timid spirit that shuts out from our contemplation the finest proofs of Divine Providence. Galen's treatise on the uses of the parts of the human body, was composed as a hymn to the

Creator, and abounds in demonstrations of a Supreme Cause; and when Cicero desires to prove the existence of the Deity from the order and beauty of the universe, he surveys the body of man, deeming nothing more godlike, as marking man's superiority to the brutes, than the privilege of contemplating his own condition, since it teaches him the ways of providence, from a knowledge of which come piety and all the virtues.

Although we are writing under the title of Animal Mechanics, the reader must be aware that we cannot proceed much farther, on mechanical principles alone. At least, before we have it in our power to illustrate particular parts of the animal frame, by reference to those principles, we must have the proofs before us that we are considering a living body. It is the principle of *life* which distinguishes the studies of the physiologist from the other branches of natural knowledge. To lose sight of this distinction, is to tread back the path, and to engage once more in the vain endeavour to explain the phenomena of life on mechanical principles. We have taken mechanics in their application to mechanical structure in the living body, because they give obvious proofs of design, and in a manner that admits of no cavil. Yet, although those proofs are very clear in themselves, they are not so well calculated to warm and exalt our sentiments, as these which we have now to offer, in taking a wider view of the animal economy.

In entering on the second department of this treatise, the reader may be startled at the subjects of discussion; but this comes also from ignorance of their nature. Much may be learned from the

observation of things familiar. Their perpetual recurrence banishes reflection respecting them, but it is the business of philosophy to make us alive to the importance of that which we have been accustomed to from childhood, and have, therefore, long ceased to observe with attention.

In the first chapter of this second part we shall continue to examine the operations of the animal body, independently of the agency of the living property. We shall consider it as a mere hydraulic machine. Following the blood in its circle through cisterns and conduit pipes, we shall point out the application of the principles of this science, as we formerly did those of mechanics, and so arrive at the like conclusions by a different course. And as we before found every muscular fibre adjusted with mechanical precision, so now we shall find every branch of an artery, or of a vein, taking that precise course and direction which the experience of the engineer shows to be necessary in laying the pipes of an engine.

Having thus surveyed the mechanical operations of the animal body, and the course of the fluids conveyed through it, on hydraulic principles, we shall consider ourselves as having advanced through the meaner to the higher objects of inquiry, and proceed to show how the principle of life bestows different endowments on the framework; how motion originates in a manner quite different from that produced by mechanical forces; how the sensibilities animate the living properties of action; how the different endowments of life correspond with each other, and exhibit power and design in a degree far superior to any thing that we observed in the mechanical adjustment of the parts, or the circulation of the fluids.

CHAPTER I

The circulation of the blood, upon the principles of hydraulics.

In tracing the course of the circulation of the blood, it is natural to inquire how far the system of reservoirs, pipes, and valves, which form the apparatus for conveying it, are constructed on the principles of hydraulics.

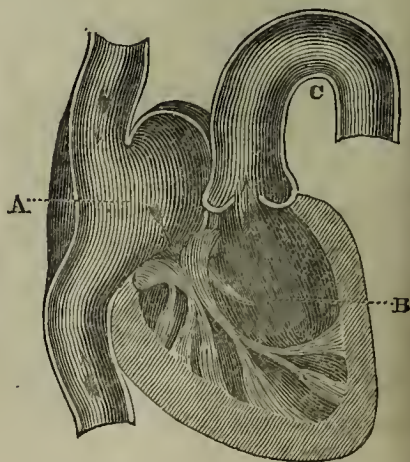
We find this difficulty in the outset, that the vessels containing the blood are not rigid, like those the engineer employs in erecting hydraulic machinery.

Instead of resembling pipes which convey water, and which receive the force of gravitation on them, they have both elasticity and an appropriate living power. The artery, the tube which conveys the blood out from the heart to the body, has a property of action in itself. Its elasticity and muscular power must derange those influences which we study in pure hydraulics.

There is to be found, notwithstanding, a great deal that is common to both, when we compare the tubes of an animal body with the hydraulic engine; the capacity of the vessels; the increase, or diminution, of their calibres; their curves; the direction of their branches;—all these ought still to be on the same principles on which experience has taught men to form conduit pipes. We ought not to be indifferent to these proofs of design, because we acknowledge that an infinitely superior power is brought into operation in the animal body, and which is necessary to the circulation of the blood. It renders the inquiry more difficult, but it does not obscure the inferences drawn from the consideration of the whole subject.

We shall first present to our readers the simplest form of the Heart. It is not necessary to detail the more complicated structure of the human heart, where, in fact, two hearts are combined; the fibres of the one continued into the fibres of the other, and the tubes twisting round one another so as to present the form which is familiar to every body. Although there are four intricate cavities, seven tubes conveying the blood into them, and two conveying it out of them, we shall, for the purpose of considering

Fig. 1.



the forces circulating the blood, and comparing the living vessels with pipes, present the heart and vessels as simple; yet with perfect truth, being, in fact, the heart and vessels of animals of more simple structure.

The action of the heart is this: the blood returns from the body by veins into the sinus, or auricle,* A, and distends it; this sinus is surrounded with muscular fibres; by the distention or elongation of these fibres they are excited, and the sinus contracts and propels the blood into the ventricle, B. The ventricle is more muscular; it is, in fact, a powerful hollow muscle; it is excited by the distention, and contracts and propels the blood into the artery, C.

We understand then that every heart must, at least, consist of two cavities alternating in their action; that the vessel which carries the blood to them is called a vein; and that the vessel which carries the blood out from them is the artery.

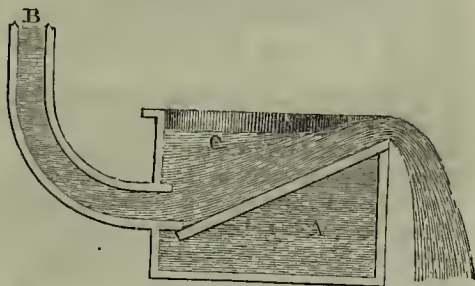
The first thing that strikes a person examining the heart is the extraordinary intricacy of the cavities, from the interlacing of its muscular fibres, and he naturally says that they appear ill calculated for conveying a fluid through them. There is an attraction between fluids and solids, he might observe, and this attraction is increased by the extension of the surfaces of the pillars and cords which he sees in the interior of the heart.

We must remind him that the blood is coming back from the body, having performed very different offices, in different parts, and has parted with different properties, in the several organs it has supplied. There is in that stream of blood which enters through the vein a new supply of fluid which has come by digestion, the material for making fresh blood, as well as that which has run the circle. These two fluids must be thoroughly mixed together, and, no doubt, this is one of the offices provided for by the intricacy of the interior of the heart.

Again, looking to the recesses of the cavities formed between the fleshy columns, and behind the valves, we might suppose that the blood would remain there stagnant. There are cavities or recesses too in the remote parts of the circulating vessels, where we

might suspect that the influence of the stream would not be felt, and a stagnation might take place. But there is attraction between the particles of fluids as well as between the fluids and their containing tubes. Let us see then how, in this figure, a stream of water carried through a cistern of water will, by its friction, draw after it the water in the cistern, and carry it above its natural level, and over the side of the vessel.

Fig. 2.



The stream entering the reservoir, A, by the pipe, B, carries with it all the water, C, which stands above the level of its upper surface. By this we see that the stream of blood entering into the heart, even if its cavities were not emptied at each pulse, as some contend they are, would draw out the blood from its recesses, so that no part could remain stagnant, but, on the contrary, all would be carried in eddies round the irregularities until they took the direction of the great artery, in which they would be perfectly combined.

The next thing to be noticed partakes of the nature of a mechanical provision—we mean the action of the valves.

We must here remark, that the opening into the ventricle is very different from that which leads out of it—the latter being much smaller. Medical writers describe this as if it were nothing to them, and a mere accident. But it must be recollected, that a stream of water entering a reservoir, is in a very different condition from that which is going out of it; it is on this principle that the mouths (*ostia* is the anatomical term) of the ventricle are differently formed, and it is this difference, which makes the structure of the valves which guard those passages so dissimilar and so appropriate. Without attention to this, we should follow our medical authorities, and call this variety in the mechanical adaptation a mere playfulness in nature.

* Auricle, from *auricula*, the flap of the ear, is a name given to the sinus, because a corner of it hangs over like a dog's ear.

It is more agreeable to us, to see a precision of design visible at the first step of this inquiry.

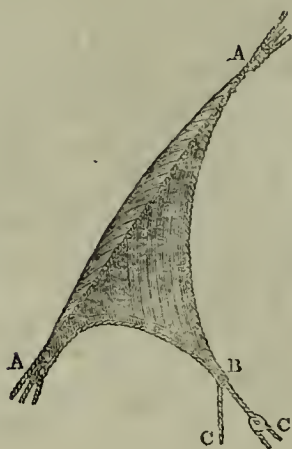
The valves of the heart are regular flood-gates which close the openings against the retrograde motions of the blood. They are not all of the same mechanical construction; and their difference deserves the reader's attention as proving design in this hydraulic machinery.

The valve which we have first to describe, closes the opening betwixt the auricle or sinus, and the ventricle, and prevents the action of the ventricle propelling the blood back again into the auricle.

It is a web or membrane, resembling a sail, when bagged by the wind. The blood catches the margin of this membrane, and distends it as the wind does the stay-sail, or gib, of a vessel, which it much resembles, being triangular and pointed. There are three of these membranes, and the valve is called *tricuspid*, or three-pointed. Three mem-

have a *bolt-rope* run along them; and on the edge where it is attached, the canvass is strengthened by being hemmed down or tabled. In the same way as the foot of the sail, or lower margin, is strengthened with the bolt-rope, just so are the valves strengthened at their edges and their corners. Where the two ropes join in the loose corner of the sail, they form a *clue*—a loop to which tackle is attached; the valve has such a corner, so strengthened, and has a cord attached. The corners of the sail are strengthened by additional portions of canvass called *patches*; so are the valves strengthened where their tendons are infixed. To the corner or clue, B, ropes are attached which are called the *sheets*, C C. These being drawn tight, spread out the foot of the sail to one side or the other, according to the direction of the wind, and the tack the ship is on; the valves have also their tackle; and, in short, we shall find a resemblance to all the parts of a sail in the valves of the heart.

Fig. 3.

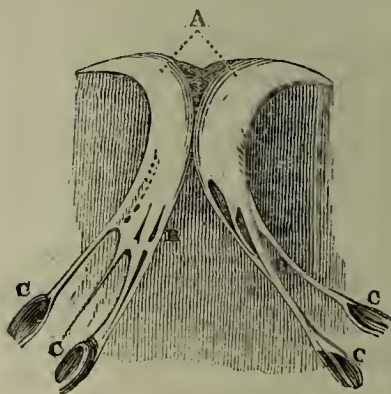


branes then, of this kind, combining and being floated back upon the mouth of the opening, effectually close it.

The illustration of the action of these valves by a sail, is so perfect, that if the reader will have patience to attend to those little contrivances which the mariner finds necessary for strengthening his canvass, and giving to it the full influence of the wind, he will have an accurate idea of the adjustment of these floating valves.

To carry on the comparison—one edge of the stay-sail is extended upon the stay A A, and tied to it by *hanks*. The edges of the sails called the *leeches*,

Fig. 4.



One edge of the triangular valve is tied to the margin of the opening, as one of the leeches of the sail is attached to the stay; the opposite corner is loose, and floats, as the sail does in tacking, until the blood, bearing against it as the wind bears against the sail, bags and distends it; the corner is then held down by tendons, for there are cords attached to the corner of the valve, as well as to the corner of the sail. These the anatomist calls *cordæ tendineæ*, B B, which in their office have an exact resemblance to the ropes called the sheets of the sail. They are delicate tendons attached to the margin of the valve, and they prevent the margin from being carried back into the auricle.

Here we find a very beautiful muscular apparatus which is necessary to the perfect adjustment of these cords. The cords are attached to small muscles called *columnæ carneæ*, C C, or fleshy columns, which at their other extremities are incorporated with the muscular wall of the ventricle itself. The use of these muscles is now to be explained. Had the tendinous cords of the valves been tied to the inside of the wall of the ventricle, without the intervention of these muscles, as the walls of the cavity approach each other during their contraction, the tendinous cords would have been let loose, and the margins of the valves carried back into the auricle. But by the intervention of these muscles, they are pulled upon and shortened in proportion as the sides of the cavity approach each other.

On the whole, then, we perceive, that this apparatus, which is as intricate as the rigging of a ship, consists of a variety of fleshy columns and cords, many of which, in fact, run across the cavity of the ventricle.

We are about to exhibit another form of a valve, much simpler, and yet we are bound to believe equally effectual; which tends to support the opinion expressed above, that besides preventing the retrograde motion of the blood, this intricate apparatus of the ventricle is intended more effectually to agitate and to mix the different streams.

At the root or origin of the great artery, called the *Aorta*, there is a firm ring to which the valves now to be described are attached. The necessity of this will appear evident, since, if the ring could be stretched by the force of the heart's action, the valves or flood-gates would not be sufficient to close the passage; their conjoined diameters would not equal that of the artery which they have to close. These valves are three in number: they are little half-moon shaped bags of thin membrane, which are thrown up by the blood passing out from the ventricle, but by the slightest retrograde movement of the blood their margins are caught, and then, being distended or bagged, they fall together, and close the passage. There are some curious little adjuncts to these valves, which ought to be explained, as showing the accuracy of the mechanical provision.

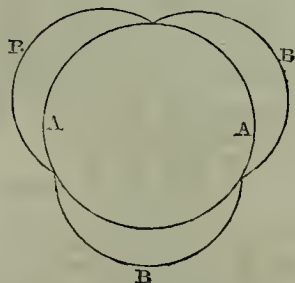
When the margin of the valve is thrown up by the blood passing out of the heart, it is not permitted to touch

Fig. 5.



or fall flat upon the side of the artery, for if it did, it would not be readily caught up by the blood that flows back; there is therefore a little dilatation of the coats of the artery behind each valve by which, although the margins of the valve be distended to the full circle, they never cling to the coats. These valves, then, are never permitted to fall against the coats of the artery, and therefore they are always prepared to receive the motion of the reflux blood.

Fig. 6.



Let this figure represent a transverse section of the root of the aorta, A A, the inner circle, is the margin of the three valves thrown up to let the blood pass. B B B are three semicircular bags formed by the dilatation of the coats of the artery at this part, receding from the margin of each of the valves—consequently, in such a manner as to leave a space between the valves and the sides of the vessel.

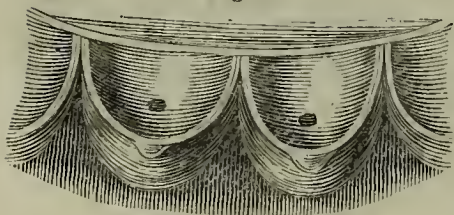
To strengthen the valves, a tendon runs along their margin like the bolt-rope or foot-rope along the edge of a sail, and these ligaments are attached to the side of the artery, and give the valve great strength.

Fig. 7.



These valves, we have said, are semilunar, consequently, when they fall together, there must be a space, A, left between them. If we put the points of the thumb, fore and middle fingers, together, there is a triangular space left between them; such a space between the convexities of the three valves would be a defect.

Fig. 8.*



Three little bodies like tongues are therefore attached to the middle of the margin of each valve, and these falling together, when the valve is shut down, perfect the septum and prevent a drop of blood passing backwards.

The valves have no power of accelerating the motion of the blood; they only prevent its retrograde motion, and cause the whole power of the heart to be employed in directing the blood forwards in the course of the circulation. But when they are ruptured, when the valve first described is rent, or the cordæ tendineæ are broken, then the membrane, which we have said is like a sail, is carried back from the second into the first cavity. It is like the sail torn from the sheets and flying out before the wind: the effect is terrible: the pulse of the heart, the whole force of which should be given to carry the blood forwards in the arteries, has half its force directed backwards upon the veins.

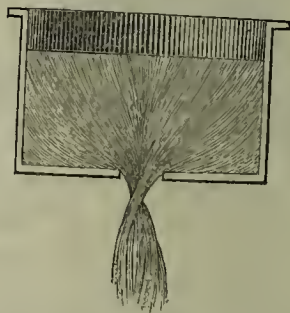
In the same manner the semilunar valves in the root of the aorta may have their margins torn. We have described

the margin of these valves to be strengthened by a tendon or cord run along their edge, like the rope which is sewed to the edge of a sail. There is an obvious intention in strengthening the valve here; but when textures of this kind become impaired in the human frame, this may give way and be torn, and then the reaction of the artery, when the heart has given its stroke, is lost; for, instead of impelling the blood forwards, the blood runs backwards into the heart. The effect of these accidents is extreme debility of circulation, with symptoms varied according as the defect falls on the circulation through the lungs or through the body—that is, whether on the right or the left heart of man. But such accidents are rare, and never take place until disease has impaired the strength of what we may call the tackle of the valve.

The next remark is founded more directly on the hydraulic principle.

This ring and these valves at the beginning of the great artery—imply a certain constriction, or diminution of the tube at this part; and we have now to show—that such a contraction of the tube at this precise part does not diminish the diameter of the column of blood. This appears an inconsistency; but if a stream of water flow from a cistern, through a hole in that cistern, the column of water will be diminished at a certain point of its exit.

Fig. 9.



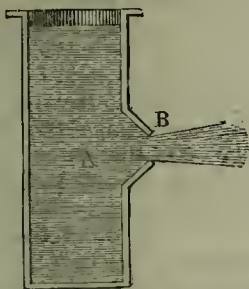
The water flowing through the bottom of the cistern may be represented by converging lines; and their united forces impelling the stream forward, contract it just beyond the exit—the *Vena Contracta*. Nature, taking advantage of this law, has constructed the narrow ring which we have shown is necessary to the accurate adjustment of the valve, at the precise part where the blood, issuing from the cavity of the ventricle, is necessarily contracted to the smallest space. The column of blood would be

* Fig. 8 represents the artery open, and the semilunar valves, like little bags, attached to the inside.

contracted at this point, even if there were no coats of the artery to confine it there.

We had thought of this as a thing indicated by reasoning, but we find that an appropriate experiment has been made which proves it.

Fig. 10.



A being the side of a reservoir, and B a short tube giving issue to the water, it will deliver as much water by this conical constructed mouth, as if the tube were of equal diameter with the hole in the reservoir. The reader will perceive how satisfactorily this indicates what is designed by the difference in the size of the mouth of the ventricle which gives entrance, and that which gives issue to the blood.

With a view to explain the motion of fluids in tubes, and finally the motion of

Fig. 11.

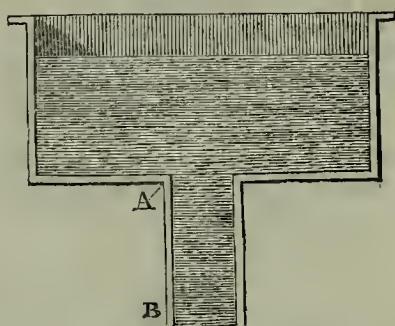


the blood in the blood-vessels, let us consider what takes place in the motion of the column of water which is not contained in a tube,

When water is poured out, and descends in an uninterrupted stream, the column contracts as it descends, until it has acquired such a velocity, that the atmosphere opposes it and scatters it; we do not mean the contraction illustrated by *fig. 9*, but that gradual diminution of the diameter of the stream, owing to the height from which it falls. We apprehend that this is on the principle, that falling bodies are accelerated as the square root of the height from which they fall. The stream being more rapid at its lower part, is necessarily smaller in diameter, until having acquired considerable velocity, the resistance of the atmosphere separates its filaments, and it becomes broader again.

A very different appearance is presented in a jet d'eau; here the ascending stream widens as it ascends. The explanation of this we conceive to be, that the fluid is retarded as it mounts, and that the stream propelled from below is forced between the filaments* of the column above, and disperses them, so as to give the column a conical form.

Fig. 12.



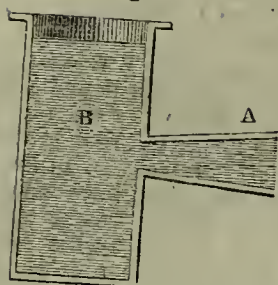
This reservoir will be emptied more rapidly if, instead of a hole in the bottom at A, the water be discharged by a tube, A B, of the diameter of the hole.—Here the column of water being perpendicular, it will be accelerated at its lower part; but instead of diminishing its diameter, as it would do, if not confined by a tube, it will draw an additional volume of water down, and accelerate the discharge.

It will be very different if the force be altogether from behind, as when water is propelled into a horizontal tube.

The tube A being conical, will discharge more fluid from the reservoir B

* Those who treat of hydraulics divide a column of water into ideal lesser columns, which they call filaments, with a very different meaning from the fibres of the anatomist.

Fig. 13.

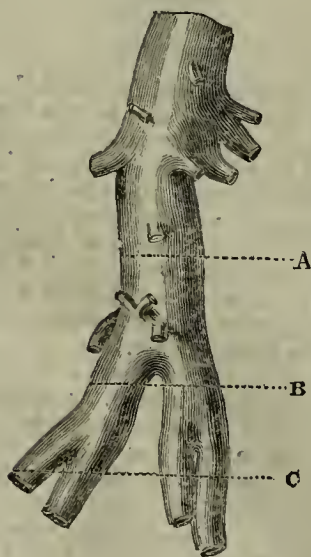


than if it had been of equal length, and its diameter throughout the same as at its commencement. Because, as it appears to us, the weight of the descending column being the force, and this operating as a *vis a tergo*, it is like the water propelled from the jet d'eau, and the gradual expansion of the tube permits the stream from behind to force itself between the filaments, and disperses them, without producing that pressure on the sides of the tube, which must take place where it is of uniform calibre. These principles will give great interest to the following fact.

The celebrated John Hunter took great pains to prove that the artery had its diameter enlarged as it proceeded from the heart, and that the areas of the branches of an artery were greater than the diameter of the parent trunk.

That is to say, the section of the trunk at A, was not so great as the two sections at B, taken together; that the

Fig. 14.

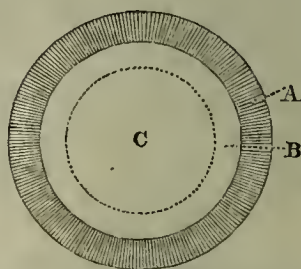


two sections at B taken together, were not so great as the four sections at C; that the conjoined diameters, therefore, of the branches of an artery were greater than the diameters of the artery itself. This fact has been sometimes expressed by saying that the artery was a cone with its apex in the heart.

When we stand by a rapid river, we can perceive that the surface of it is not level. The stream is rapid in the middle, and there the water is highest. The friction of the water against the bottom and the sides, retards the stream, whilst the greater velocity of the current in the centre, draws the water to it, which is the reason of its elevation there.

For the same reason, if an engineer estimate the quantity of fluid to be delivered through a tube without estimating the friction of the sides, he will be disappointed in the result of his calculation; for, as the water of the river is delayed by the bottom and sides, so is the fluid in the tube retarded, by

Fig. 15.



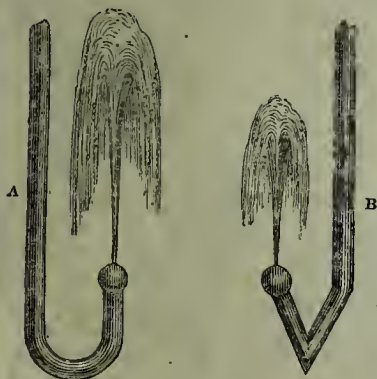
the attraction or friction between the water and the tube. And, if we can imagine a section representing the tube and the flowing water, A will be the solid tube, B the water retarded or arrested by the friction against the tube, and the space C, within the inner circle, would represent that part of the stream which is in uninterrupted flow. The engineer will therefore lay a tube larger than would be necessary, were there neither attraction nor friction between the solid and fluid. It must farther appear that the smaller the calibre of the tube, the surface of attraction or friction will be proportionally greater. Does not this explain the anatomical fact which we have been contemplating, that the area of the smaller branches is comparatively larger than the trunk from which they are derived?

Two beneficial effects result from this; for we must observe that the blood-vessels of the body are reservoirs

as well as conduit-pipes. A man of middling stature has 33 lbs. of blood in his circulating vessels: if the vessels did not enlarge as they receded from the heart, there would be no place for the deposit of this great quantity of blood. The advantages, then, of this particular form are, *first*, that a quantity of blood necessary to the economy is contained within the vessels; and, *secondly*, that the blood is more easily urged forwards by the action of the heart. The reader will not now be surprised in learning, that a pipe of a conical form, that is, enlarging as it proceeds, gives the least interruption to the flow of water from a reservoir.

Water flowing in a tube will be retarded by any sudden angle in the tube. If the ajutage of a jet d'eau have not a gentle and uniform sweep where it is turned, the jet of water will not reach the height which it ought to do by calculation of the height of the reservoir of water from which it descends, it will

Fig. 16.



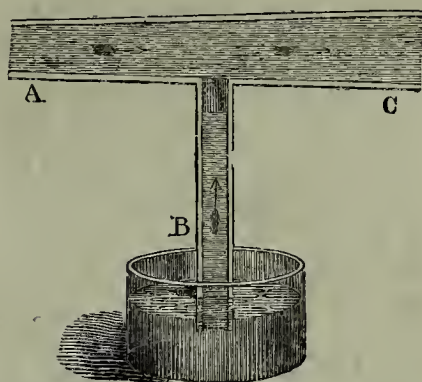
go higher from the tube A than from B. This circumstance explains the uniform and parabolic curve which the great artery of the body takes in first ascending from the heart. It explains also why the branches of the great artery go off at different angles, according to their distance from the heart, or, in other words, why they pass off at smaller angles with the stream the farther the artery recedes from the heart.

In the distribution of water-pipes, it is very necessary to attend to the angle at which the small pipe is attached to the greater one, not only because a pipe being bent abruptly causes loss of motion from the impulse of the fluid against the side, but also from another well known law of hydraulics,

If a pipe be fixed into another so as to join it at an angle contrary to the direction of the stream, the discharge into that lateral branch from the larger tube will not only be much smaller than we might estimate by the diameters of the tubes, but, in certain circumstances, it will discharge nothing at all; nay, on the contrary, the water would be drawn from the lesser tube into the greater, until the lesser tube be emptied, and air be sucked in.

Bernouilli found that when a small tube B was inserted into the side of a horizontal conical pipe A, in which the water was flowing towards the wider

Fig. 17.



end C, not only none of the water escaped through the small tube, but the water from a vessel placed at a considerable distance below was drawn up through the tube B into the pipe A.

With these facts before us, we turn with interest to what the anatomist too often contemplates with unconcern, we mean the different curves in the branching of the arteries and veins; for by this law of hydraulics, the junction of the branches and trunks of the arteries and veins ought to be different, as the one vessel, the artery, carries the blood out from the heart, that is, from trunk to branch—and the other vessel, the vein, carries it in the opposite direction towards the heart, or from branch to trunk.

And in matter of fact, their branchings are very different, and characteristic of the vessels.—We have heard a teacher of anatomy express himself in this manner. “The arteries are active and powerful vessels, which carry the arterial blood out from the heart—and they receive the forcible impetus of the heart.

When they are wounded, the man bleeds to death;—therefore, nature conveys these vessels into the recesses of the body, taking advantage of every protecting bone—conveying them so that the bones and the muscles protect them. There are no irregularities in their course, and their branches go off at a determined angle, and never irregularly; but the veins," he would continue, "are vessels of less importance—they convey the blood back to the heart, with a languid motion, and if they are wounded the blood flows with so diminished a force that you can stop it with the pressure of your finger; accordingly, nature is more negligent of them, they run in all their courses irregularly—some deep, some superficially; and their branches join their trunks with awkward irregular curves and elbows."

This is in good feeling, and is in part true; but it contains somewhat of the error which runs through most anatomical discourses, of supposing things are irregular, as if the objects in view were inartificially and imperfectly attained. From inattention to the hydraulic principle, he seemed not to have considered, that the connection of trunk and branch must vary according to the direction of the stream,—that the direction of the branch, which is adapted to lead the stream from the trunk into the branch, must be altered, when the design is to convey the fluid from the branch into the trunk.

Fig. 18.



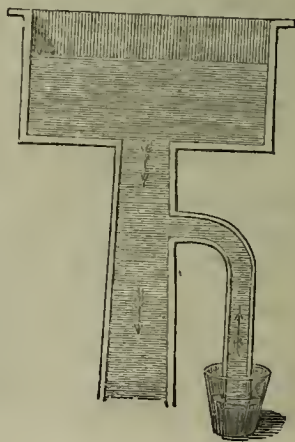
The reader will now understand, that the branch of the artery (*fig. 18, No. 1.*) gently diverges from the direction of the stream, while the branch of the vein, in *No. 2*, enters abruptly and at right

angles. We may illustrate this, by observing, that if we could suppose the vein substituted for the artery, and the artery for the vein—if the vein carried the blood outwards, instead of towards the heart, and the artery conveyed the blood back to the heart, the blood could not run in the circle; it would be retarded, and congestion would take place, somewhere in its course.

We have seen by the demonstration above, that if the veins of the human body were rigid tubes, and if a hole were made in their sides, air might be drawn in, instead of blood flowing out. This is a matter of vital consequence, for if a very little air be blown into the veins of an animal, it dies in an instant, and there is no suffering nor struggle, nor any stage of transition, so immediately does the stillness of death take possession of every part of the frame.

In conversation with Napoleon's celebrated surgeon, Baron Larrey, on the case of a young man wounded in the neck, he said he had no hesitation in declaring the cause of death to be, air drawn in by the veins of the neck, and he quoted instances occurring at the battle of Wagram. These circumstances greatly increase the interest of an experiment made by Dr. Barry, who found that on introducing a tube into the vein of the neck, and placing the other end of the tube in a vessel of water, the water rose during inspiration. The difficulty of explaining this, arises from those veins being membraneous tubes, and consequently compressible; but in the act of inspiration, not only are the ribs and breast-bone raised, but the muscles of the neck attached to the collar-bone rise from the veins of the

Fig. 19.

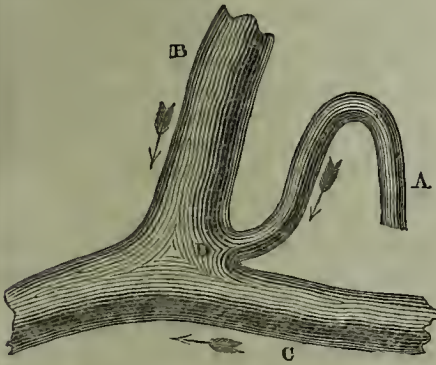


neck. By this means, instead of suffering the compression of the incumbent parts, the atmospheric pressure is taken off the veins, they are brought to the condition of rigid tubes; and the principles of hydraulics explain the rest. Thus *fig. 19* is a reservoir emptied by a perpendicular tube, into which a smaller tube is inserted. The water descending by the larger tube, will draw the water up through the lesser tube, so as to empty the glass, in which its lower end is immersed.

We shall here give an example of the manner in which the trunk of the absorbent system joins the venous system, a circumstance which has not escaped the notice of anatomists. The absorbing or lymphatic system, consists of a set of vessels different from arteries and veins, which imbibe by a sort of capillary attraction at their extremities, and convey their fluids towards the centre, without any such impulse as the proper blood-vessels receive from the heart. The stream in the trunk of this vessel has no force to impel it into the stream of blood in the veins; it enters, therefore, in this manner.

A is the trunk of this system, called the thoracic duct, B is the great jugu-

Fig. 20.



lar vein descending from the head, and C the great vein coming from the arm. These veins join at an angle, and the streams from them, in the direction of the arrows, leave a point between them at D, where there is no pressure. If two tubes enter into a larger tube obliquely, and the water be flowing from the lesser tubes into the greater one, and if a hole be bored at the angle of their union, the water will not escape at that hole. Therefore, the fluid from the thoracic duct A, meets with no impediment at the point D; when entered, we have

seen, by a former diagram, how the attraction of the more forcible stream will draw the contiguous fluid after it. By this contrivance, if we may use the word, the fluid in the absorbing system finds access to the red blood, and is carried into the heart.

We might continue this subject, by considering the influence of respiration on the circulation; but we shall pursue the enquiry into the hydraulic principles, as applicable to the circulation, independently of pneumatics.

The law of inertia, which is of easy comprehension as it regards solids, is also applicable to fluids; it is easier to keep a column of water in a pipe in motion, than to put it into motion from a state of rest.

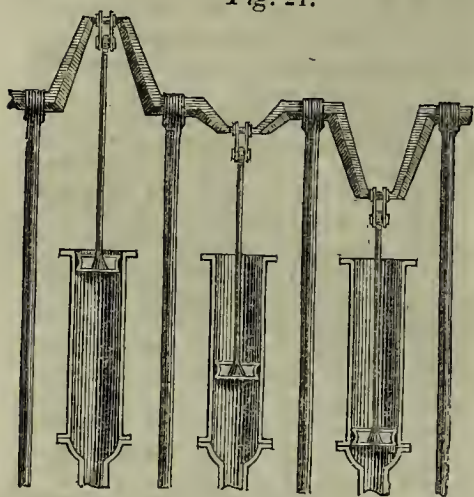
In a forcing pump, when after each movement of the piston the column of water becomes stationary, power is unnecessarily lost by bringing the column of water, which is in this state of rest, again into motion; but if a second blow of the engine be given to the column of water whilst it is yet moving, it is found to be more easily pressed forward, and no part of the force is lost in urging it from a state of rest into motion. This is evinced in the contrivances of the engineer. He employs two forcing pumps instead of one, and he so applies his lever, as to operate alternately on the one and the other; to the end that the water in the pipe may be kept in uninterrupted motion. Let us apply this principle to the circulation of the blood.

If the heart were the only power forcing on the blood, there would be a cessation of motion after each pulse of the heart, and therefore a great part of its power would be lost. This explains why there is a power in the artery as well as in the heart. The artery being muscular, seconds the operations of the heart; its muscularity, and the muscularity of the heart are powers exercised alternately, and which, acting like the double stroke of the engine, permit no interval to the motion of the column of blood. If the heart had to act upon a column of blood at rest, not only much of its force would be unnecessarily exhausted, but it would be excited to propel an inert body, and a dangerous shock would arise from the resistance.

If we pursue this subject, and inquire what is essential to such a hydraulic machine as we are contemplating, we shall perceive that the engineer meets with a difficulty in adjusting the powers

of his two pumps, and finds an interval, or pause, in the application of their forces.

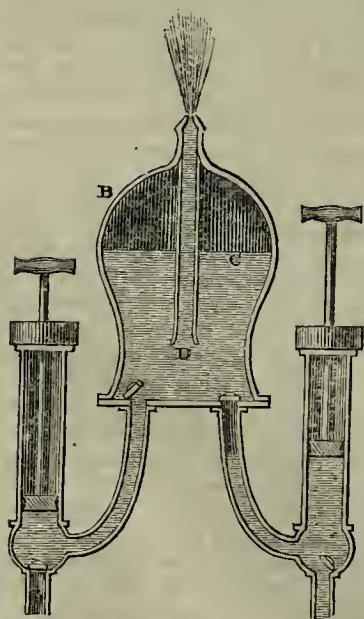
Fig. 21.



To obviate this, he makes three cylinders, the pistons of which are moved by a crank, which so orders the descent of the pistons as to fill up this interval, so that one of the pistons shall be always descending; and these pumps propelling the water into a common tube, there is no interval to the motion of the fluid through it.

By this example we are led to look for something corresponding in the ma-

Fig. 22.



chinery of the circulation. We find no third active power, however; yet we

find a quality in the blood-vessels which answers the purpose much better. But to comprehend this, we must observe that the engineer has a more admirable contrivance than this of a third pump to adjust the action of the other two.

He confines a body of air which, by its elasticity, performs the office. The pipes of two forcing pumps are carried into the reservoir B; they convey the water up to C, by which time the air is compressed, and its elasticity thereby increased, that elasticity is exerted without interval, and, acting on the water C, propels it into the tube D uninterrupted.

Just such an elastic property is possessed by the arteries. The great artery which goes out from the heart, as we have had repeated occasion to observe, makes a sweeping curve; it is capacious, and is the most perfectly elastic of any thing in nature. Here then we have the three powers which the engineer finds necessary to employ. We have the alternate action of the heart and artery, and we have an elasticity which, though passive, is essential, both to the uniform flow of the blood, by filling up the interval in the action of the two powers, and to the safety of the engine itself; for without this elasticity there would be such a jar as must speedily destroy the mechanism.*

There is nothing more admirable than the influence of this elastic power; it is greatest in the coats of the artery near the heart, weaker in the coats of that artery as it recedes from the heart; this very evidently declares its use: but we shall take a more sufficient proof, although an unhappy one.

As life advances, the arterial system loses much of its elasticity, and becomes rigid. This is so common an occurrence that we can no more call it a disease, than the stiffened joints of an old man; it is the forerunner or the accompaniment of the decline of life. But this sometimes takes place too early in life, and to an extreme degree; and from its effects we must call it morbid; for it not unfrequently happens that the muscular power of the heart being still entire and vigorous, the arteries can no longer sustain it. They are not now endowed with that power which, yielding

* But does the blood flow uniformly? Not precisely so in the arteries, since the stroke of the heart is more powerful, or rather more concentrated, than that of the arteries. During the contraction of the ventricle of the heart the artery is dilated; but it is never emptied; and the flow of the blood forwards in the course of the circulation is not for an instant interrupted.

to the heart's action, resists, and recoils the more it yields—which takes off all sudden shock, and which in yielding wastes no power, since on its recoil it gives as much force to the acceleration of the blood, as was lost of the heart's action. The artery then becoming rigid, yields indeed to the heart's impulse, but has no recoil. It is permanently dilated or enlarged. It is now called aneurismal. A stronger impulse from the heart, excited by inordinate action or passion, chips and bursts the now rigid coats of the artery. If the breach be sudden, it is death; if it be gradual, a pouch forms—a true aneurism. And now we have the proof we require; for this bag coming to press upon the solid bones, they are destroyed. That action of the heart which was so lightly and so easily borne whilst the vessels were elastic, now beating upon a solid structure, in a short time destroys it. Thus we are led to a more accurate knowledge of the fine adjustment of the active and resisting properties in the circulating vessels during youth and health, by what takes place on a very slight derangement of those powers.

CHAPTER II.

The Illustrations from Mechanics may be carried too far. Peculiar properties of Life in the Body. They differ in quality. They have an adjustment to each other, more admirable than the Mechanical connection.

WE are the more desirous of entering upon this subject, that we may prevent the reader from founding a false conclusion upon the very mode in which we have hitherto proceeded, that of showing design in every part of the animal structure by taking our illustrations from the mechanism of the body.

When we have admired the connections of the several parts, or organs, thus made manifest by comparison with machinery, we may go too far, and say, that the material structure and mechanical relation are to be found in still greater minuteness and perfection in the finer textures of the body, proceed to call this organization, and erroneously conclude, that out of organization comes Life. The very term organization misleads; yet it implies something constructed, in which one part cooperates with another; but nothing more. Taking the body as a whole, there are un-

doubtedly instances of such coöperation, but it is in vain to seek the explanation of life from this; since life exists in simple and uniform substances, where there is neither construction nor relation.

Now, although there are mechanical construction and relation, as we have seen, in bones, muscles, and tendons, the phenomena of the body result from a dependence established among the living properties, not the mechanical. The highest medical authorities have seen reason to conclude that life is an endowment, not resulting from organization or construction, but, on the contrary, producing it; in other words, that the living principle attracts the new matter, arranges it, and, in order to its continuance and perfection, alters it, and effects a continual revolution in it. For there is nothing more curious than the uninterrupted and rapid change of the material of the animal body, from the first pulse of life to the last breath that is drawn; of which we shall give abundant proofs before we close this inquiry.

In first approaching the subject we are blinded by familiar occurrences, and cannot comprehend all the links by which the visible phenomena of the living body are produced. Probably most of our readers believe motion to be a necessary consequence of life, and the very proof of its presence. The peasant stirs up an animal with his staff, and if it does not move he is satisfied that it is dead; and such is the experience of mankind. We do not reflect that many different qualities of the living powers must be exercised before sensibility is shown in its visible sign, the motion of the creature. It is not necessary that the parts shall lock into each other like the cogs of wheels;—the connections established are of a different kind altogether. Each part possesses a property of life entirely distinct from the other, and this property of life may exist in the individual part (for a time at least) without that cooperation of the whole which is necessary for the motions of the animal.

This quality of life is, in one respect, like gravitation in matter; that is, when the mass is broken into parts, each division has its proportion of the endowment, and so the separated parts of a living creature possess life. But here the resemblance ceases; gravitation is the same quality in every part, and uniform in its effects, whilst the life is exhibited

by qualities differing in every part of the animal body. Did these parts possess qualities exactly similar, they would remain at rest, and though combined, they would not influence each other. It is the different powers brought into combination that produce the motion of the whole animal.

If a man fall into the water, and is dragged out motionless, and has ceased to breathe, each part of his body may still possess its property of life. Although the combinations have been destroyed, he may be revived by exciting action in some part of his system. Life still remains in brain, and nerves, and heart, and arteries, and in the muscles, which should enable him to breathe; but the mutual influence, the bond of their united operations, is broken. We may take the analogy of a machine, and say that the wheels are stopped; but this is in fact a very different thing; it is the operation of the living influence that is stopped; for we repeat that nature (by which, of course, is always to be understood the Author of Nature) has combined the organs not mechanically, but by properties of life.

Artificial respiration draws after it the action of the heart, because the sensibility of the heart is made respondent to the lungs. Pulsation of the heart, excited by the motion of the lungs, is followed by the action of the arteries; these organs in operation, drive the blood through the frame, and by the circulation the susceptibility of each part to impression, which had been weakened, is restored. Action and reaction are reestablished; but these actions are not like those of a machine, they are living properties, sensibility in one part, contractility in another; and after a variety of these internal sensibilities have been for some time in operation, the man gives outward token of recovery.

So a person recovering from fainting, after sobbing and irregular breathing, has the respiration renewed; in succession other parts recover their sensibility and resume their places in the circle of relations; the skin is capable of being stimulated, and the limbs are capable of motion; the eyelids are opened; by and by the nerve of the eye is sensible to light, and the nerve of the ear to sound; and, finally, the faculties of the mind are roused, and its control over the body reestablished. The whole separate endowments of life in the different parts re-

sume their offices;—the last in the train; only, the property of the muscle to contract is alone observed by the uninformed, and voluntary motion is the token of entire restoration.

We can imagine a half-learned person to act very foolishly in the attempt to restore the apparently drowned. He has been told that we draw in vital air, and breathe out what is unfit to support life; he imagines that it can be of no use to distend the lungs of the drowning person with his own breath, and precious time is lost. Whereas, the mere distension of the chest, that is, of the lungs, followed by the compression of the chest, and again by the distension, and so on alternately, is the *play of the lungs*, which by sympathy draws the heart into action, and in succession all the vital organs. This is not what chemistry teaches; chemistry shows us that the vital air influences the blood; and it is true that the blood, being refreshed or impregnated with the vital air, renews the properties of life. But this effect on the blood could never take place, unless there were some previous consent or sympathy, putting the organs into operation. We repeat that the consent of organs is not the effect of mechanical adaptation, or of chemical action, but of relation established among the vital properties.

If a man be struck by lightning, he has not merely the vital operation of respiration stopped, as in the case of the drowning man, in whom every organ continues to possess its property of life; he is not like a man struck on the head, where one vital organ is so disturbed that the circle of vital actions is broken; in this instance the electric fire passes through every fibre and every organ; all the qualities of life, whether residing in the brain, nerve, or muscle, are instantaneously destroyed; and the moment of death is the commencement of dissolution.

Mr. John Hunter illustrated this somewhat familiarly. If you bruise the head of an eel, its body writhes; but if it be taken by the tail, and struck on the flag-stone, so that every part of its body receives the shock, then all the parts are killed, and it remains motionless. When an animal is killed by that violence which injures one important organ, the property of life remains for a certain time in every part; those parts have no correspondence, and there is no outward token of life; but the vital

principle is still capable of exhibiting one of its most important properties ; it arrests the operation of those chemical affinities which belong to dead matter.

Thus the reader perceives, that, although he be led on to comprehend the design or intention manifested in the structure of the body by mechanical instances, or comparisons, it is when we contemplate the influence of the living principle, that we have a higher conviction of the Omnipotence, which has formed every creature, and every part of each creature, with that appropriate endowment of life, which suits it to act its part in the general system.

We must learn to distinguish between the death of the animal, and the death of the parts of the animal—between apparent death, and dissolution, or the separation of that quality which distinguishes living matter.

Viewing the subject generally, as Mr. Hunter said, there are not two kinds of matter, but two conditions of matter. It is at one moment forming beautiful combinations, as in the flower, through the principle of life, and, at another, it is cast away as noxious, undergoing changes by decomposition, from chemical processes solely. The want of combination in the whole animal body exhibits apparent death. The loss of life in all the parts of an animal body, is absolute death, and the material becomes subjected to the influence of the chemical affinities, instead of being urged into motion by life.

The jackstone produces motion in one part of a machine ; that, varied by mechanical influence, is communicated to a second ; from the teeth of one wheel it is communicated to the corresponding leaves of the pinions, and from the pinions to the fusees. But what a base notion it is to suppose that the mere property of weight in the jackstone is like the influence of life !

The weight is the power, in the language of mechanicians ; but it does not reside in the parts of a machine, nor does it exhibit different qualifications in these parts. Separate them, and they are nothing. On the contrary, no one part of an animal body is in this manner dependant on another for its property of life. The property is inherent in the part itself, and the wonderful thing is that each property in the several organs corresponds with the others, so as to form a circle of vital operations. There is no transmission of power, in all this,

from part to part—no train of connection to be traced as from the jackstone, or the spring, along the parts of the machine. There is, therefore, in truth, no resemblance between machinery and the influences in operation in a living body. What is to be admired in a living body is not merely the adaptation of bones, muscles, and tendons, forming a mechanical apparatus, but rather the different qualities which life bestows upon different parts ; these qualities put the parts into relation each according to its place in the circle of the economy ; and among innumerable properties of life in the individual parts, produce that perfect cooperation as if one principle only actuated the whole.

When a person moves under the direction of the will, nothing can be more simple to our understanding, because we do not attempt to trace the links, far less to estimate the powers in the several parts influenced during this familiar action. But if there be the slightest diminution of sensibility of one nerve so that it shall not transmit sensation ; or if there be any disturbance which retards in the least degree the transmission of the will along another appropriate nerve ; if the muscle be benumbed, or have lost its irritability ; if the action of the blood-vessels has been either diminished or increased beyond their ordinary course, either in the organs of sense, the brain, or nerves ; we are appalled by the consequences. The impressions of things are not felt ; the senses are unexercised ; the limbs remain inactive ; one half, or the whole, of the body is a load, as if there were a living being in a dead body—a body whose parts refuse their office, appearing dead though they are not so. The correspondence of their living qualities has alone been disturbed ; the movement which results from the whole is stopped, and there is apparent death.

What confusion then must be engendered in the minds of those who would confound the phenomena of life, as presented in the entire framework of the body, with those separate qualities of life, which, residing in the several parts, must enter into combination for the motion of the whole ! The next step of this unphilosophical manner of treating the subject, is to make the organization the source of the living property,—as if any combination of organs could produce life,—as if those organs could have motion without the distinct endowments of life in their separate parts,—as if

they cooperated mechanically, and not from the correspondence among their living properties. Those who thus reason mean to say, that parts are made so finely as to move of themselves, one part propelling another, and the motion of the whole producing life. It is quite clear that this confusion of ideas arises from contemplating the phenomena of the perfect animal, in which all intermediate influences are confounded. On the other hand we present this proposition.

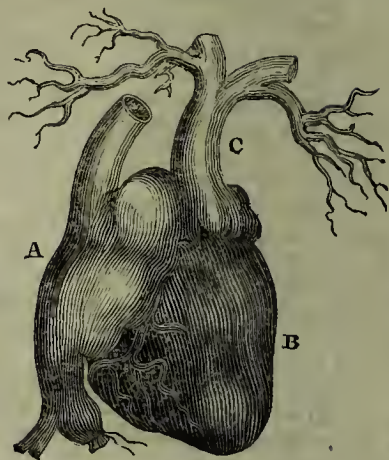
The several *simple* substances of a living body have each an endowment of life bestowed upon them. Let us take the obvious qualities, of sensibility—the power of transmission—and the power of motion; each of which is appropriate to a particular substance. When these qualities are put in relation, impressions may produce motion, and thus there are three distinct properties of life brought into operation. Where is the organization or construction here? Without those living endowments these parts would be inoperative, in whatever juxta-position placed. The mechanical construction of the body is one thing: and we are able to admire it, because it can be illustrated by comparison with our own contrivances; the combination of living properties is another and an entirely different thing.

We here reach the limit of philosophical inquiry. Hitherto all has been flattering to the pride of the creature; but we must now humbly acknowledge the inscrutable ways of the Creator; and ceasing to trace the origin of life, more than we do that of gravitation, we should be occupied in observing its laws, not in exploring its source.

We shall take an instance to illustrate the difference betwixt the mechanical connection of parts, and their relations through the living properties. And it will, at the same time, show how curiously the living properties and the mechanical properties are made to correspond with each other.

A stream of water is converted into a mechanical power; it fills a cistern, which is attached to a lever; the cistern descends by the weight of water; by its descent a valve is pushed open; the water escapes, and the cistern ascends, and remains so, till the stream flowing into it again, depresses it. Thus the regularity of the supply of water gives regularity of motion to the machine. Compare this with the heart.

Fig. 23.



We may describe the heart as consisting of two cavities, the one called the *Auricle*, and the other the *Ventricle*. The sinus A (fig. 23) receives the blood returning by the veins, and gradually filling, like a cistern, it becomes so distended, that its muscular power is excited; it contracts, and delivers the blood with a sudden impetus into the second cavity, or the ventricle B; which, in its turn, excited by the distension, contracts, and propels the blood into the artery C. Here the action of the heart is accounted for, by its mechanical distension with the blood: and the regularity of its motions necessarily corresponds with the regularity of the supply. The distension produces action, and the propulsion of the blood from the cavity allows a momentary state of rest, until another volume of the blood excites another pulse.

But we have now to observe, that when this irritability or muscular power was bestowed upon the heart, it was directed by a law entirely different from the irritability, as possessed by other muscles. A property of alternate activity and rest was given to it, quite unlike the contractility of other parts; and accordingly when the heart is empty, when there is no distension of blood at all, the two cavities will continue their alternate action. Nay, if the heart be taken from the animal recently dead, it will continue to act in regular successive pulses, first the one cavity, and then the other, and so on successively for a long time, until the life be quite exhausted. The two cavities will thus continue in alternate action, as if they were employed in the office of propelling the

blood, when there is no blood contained within them. It is superfluous to observe, that no such thing could happen in the case of the cistern and lever, were the stream of water to cease running.

Thus we distinguish two things quite different, a mechanical or hydraulic provision, by which these little cisterns, the auricle and ventricle, shall be regularly supplied, and alternately filled and emptied—and the property of contraction in the heart; not a mere property of contraction from irritation, as in the other muscles, but a property far more admirable, since the irritability or power of contraction of the part, is ordered with a reference to its office—that it shall contract and relax in regular and rapid succession, and continue its office unwearyingly through a long life. The living property of the heart exhibits a variety adapted to its office, and a correspondence still more admirable than the mechanical relation.

We are thus particular in distinguishing the mechanical adaptation of parts, from the cooperation of the vital influences residing in the several parts; for there are many who will take the illustration from mechanics, and stop their inquiry there, and who entertain a confused notion of the dependance of the life of the body on its mechanism.

Another mistake, which some philosophical inquirers entertain, is to fancy that the principle of life is of a galvanic nature. There is indeed an unwillingness in men to acknowledge that their powers of reason are exhausted, and that they have arrived at an ultimate stage; they would fain set up some contrivance to hide the humiliating truth. Whatever notions have prevailed in the schools at different epochs, of heat, electricity, or galvanism, we find an attempt to explain the phenomena of life by an application of the powers, with which they have been successful in their physical inquiries. Experiments without reason are equally delusive with hypotheses; those who will not give themselves the labour of thought, desire to witness striking phenomena; wonder-struck, they believe that they are engaged in experimental investigation, when their state of mind is little better than idle amazement. A calf's head is made to yawn, or a man cut down from the gallows to move like a figure of cards pulled with strings; the jaws move, and the eyes roll, and this is done by conveying the galvanic shock to the nerves; here it is supposed

that nothing less than the principle of life itself can work such wonders, and that galvanism is this principle.

Putting aside the circumstance already stated, of life exhibiting totally different phenomena in union with different parts, is there any point of resemblance between galvanism and life? Does tying the nerve stop the influence of galvanism, as it does the influence of life? Does galvanism course along a cord when it is surrounded by matter in contact with it of the same nature? Can life pass out of one body into another, like heat, or electricity, or galvanism? Can *they* be contained by a thin membrane? Does life pass equally through all the parts of a moist animal body as one uniform influence, like galvanism?

In no circumstance is there a resemblance, and the whole phenomena resulting from galvanism transmitted through an animal apparently dead, are fairly to be attributed to its being a high stimulus conveyed through the moist animal body, and exciting the powers which remain insulated in the several parts; and in exciting those forces, far from renewing them, it exhausts them altogether.

The uses made of galvanism in the explanation of the living phenomena, should make sensible men very cautious how they carry the legitimate inductions of chemical science into another department. They will not submit to call the irritability or contractility of a muscle an endowment of life, but seek to explain it by organization. They employ the microscope; they find the ultimate fibre to be some thousandth part of an inch in breadth; they see plicæ or folds; they imagine them to be cells into which the fibres are divided; they furnish these cells with two different gases, and explode them by some galvanic influence of the nerves; and the explosion by dilating the cells in one direction, causes the contraction in another. This is the theory of muscular action at the period of the discovery of the gases; and some such idle hypothesis, supposed applicable to the laws of life, accompanies every considerable improvement in chemistry.

In the most modern and the most popular French work on Physiology, by Mons. Richerand, he says, "What appears to me by much the most ingenious opinion, and which carries with it the greatest probability, is that which supposes the contraction of the muscle

to depend on the combination of hydrogen, carbon and azote, and other combustible substances which exist in the fleshy fibre, with the oxygen conveyed to them through the arteries." But he adds, 'as if he had perfected the theory,' "it is also necessary to suppose, that a nervous fluid is directed through the muscle to determine the decomposition, as the electric spark forms water out of two gases."

Such is the chemical theory of muscular motion; it betrays an entire misunderstanding of the phenomena of muscular motion, and of the beautiful provision in every muscle for its appropriate office. The muscles, which are subservient to the organs of sense, differ in their operations altogether from the voluntary muscles of the limbs. The hollow muscles, as they are termed, those which carry down the food, and which carry round the blood in circulation, vary in their time and manner of acting according to their offices; but what conception can he have of such adjustment of powers, who is entertaining himself with a theory, that supposes a sudden explosion to take place in the fibres of the muscle at their time of action? Inductive reasoning, which has carried men to the highest acquirements in physical science, is here laid aside; conjectures totally inconsistent with the phenomena of life are employed in its stead; and the useful philosopher becomes a very indifferent physiologist.

CHAPTER III.

Of Sensibility.

UNDER this head are comprehended, not any sentiment or feeling of the mind, but the sensations of the body.

We form our notions of sensibility from that of the skin; and it is no doubt necessary that we should do so. It is in constant communication with things around us, and affected by their qualities; it affords us information, which corrects the notions received from the other organs of sense, and it excites our attention to preserve our bodies from injury. We are so familiar with the painful effects of injuries upon the surface, that there is nobody who does not imagine that the deeper the injury, the more dreadful the pain. But, on the contrary, it is a well-established fact, that to such irritants as would give the

skin pain, the internal parts are totally insensible. And it is equally certain, that though the nerves, the instruments of sensation, are incapable of producing any perception without the brain, yet the brain itself, the part which is the seat of intellect, and to which every impression must be referred before we become conscious of it, is itself as insensible as leather. These considerations show us that sensibility to pain, is not a necessary result of life, and they naturally lead to the inquiry for what purpose is sensibility bestowed, and how is it distributed in the body?

We have first to show that the skin has sensibilities exactly suited to the functions it has to perform. Science no doubt informs us, that warmth and cold are only relative degrees of heat; to the skin they are distinct sensations, and excite in different ways both the mind and the bodily functions. Cold braces and animates to exertion, whilst the warmth which is pleasant to us, is genial to all the operations of the animal economy. Their alternations are the most constant sources of our enjoyment, and at the same time conduce to exertion and to health. All this, however, belongs to the skin exclusively: parts internal, although peculiarly sensible to their proper stimulus, give no indication of sensibility to heat; if there be internal sensations of heat, they are morbid and deceptive. Molten lead would produce pain and death being poured into the interior of the body, but the sensation of burning is a property of the surface only. It is the excess of that particular sensation, which is calculated, like the other endowments of the skin, to suit the medium in which we live, and to force us to the regulation of the temperature necessary to preserve life.

Touch, or the sensibility to bodies pressed upon the skin, is likewise a distinct and appropriate sense. The sensibility of the skin to pricking, cutting, or tearing, is also in curious contrast with the sensibility of the solid internal textures, as bone, cartilage, and ligament. We have arrived at the full comprehension of this subject very slowly. Disagreeable experiments have been made, but the following is as interesting as it was innocently performed. A man who had his finger torn off, so as to hang by the tendon only, came to a pupil of Dr. Hunter. "I shall now see," said the surgeon, "whether this man has any sensibility in

his tendon." He laid a cord along the finger, and, blindfolding the patient, cut across the tendon. "Tell me," he asked, "what I have cut across?" "Why, you have cut across the cord, to be sure," was the answer. By such experiments it became very manifest, that bone, gristle, and ligament, were insensible to pricking, cutting, and burning. Were they, therefore, insensible? The reader will answer—Surely, it is a matter proved. But before we finally decide, let us take this into consideration,—that the sensibilities of the body differ in kind as well as in degree; and every part has its peculiar kind, as well as its degree; and every part has its kind of sensibility with reference to its function, and also with reference to its protection from violence. If the membranes between the bones of our great joints, or the cords which knit the bones, were sensible in the same manner and degree with the skin, we should be incapable of motion, and screwed to our seats; as the man appears to be who has a violent attack of acute rheumatism.

But although these bones and cartilages, or gristles, and ligaments, be not sensible as the skin, or the surface of the eye, they possess that which is suited to their condition, which permits their free use, and yet limits that too free exercise which would be injurious to their textures, or raise inflammation in them. The ligaments and tendons, then, which are insensible to pricking, cutting, and burning, are sensible, nevertheless, to stretching and tearing! It is remarkable that such men as Dr. Hunter and Haller, the luminaries of their science, should have held the opinion that the bone and the membrane which covers it (the *periosteum*), the gristles or cartilages, the ligaments of joints, and the tendons of muscles were insensible parts, and yet be in daily attendance on those who suffer the pain of a sprained ankle, where there are no parts to suffer but those enumerated, and where the pain, excessive in degree, was felt in the instant of the sprain. These considerations explain to us that pain is the safeguard of the body. This capacity of conveying painful impressions to the mind is not given superfluously to all parts; on the contrary the safe exercise and the enjoyment of every part is permitted without alloy, and only the excess restrained.

This subject is finely illustrated by the apparent insensibility of the heart.

The observation of the admirable Harvey, the discoverer of the circulation of the blood, is to this effect. A noble youth of the family of Montgomery, from a fall and consequent abscess on the side of the chest, had the interior marvellously exposed, so that after his cure, on his return from his travels, the heart and lungs were still visible and could be handled; which when it was communicated to Charles I., he expressed a desire that Harvey should be permitted to see the youth and examine his heart. "When," says Harvey, "I had paid my respects to this young nobleman, and conveyed to him the king's request, he made no concealment, but exposed the left side of his breast, when I saw a cavity into which I could introduce my fingers and thumb; astonished with the novelty, again and again I explored the wound, and first marvelling at the extraordinary nature of the cure, I set about the examination of the heart. Taking it in one hand and placing the finger of the other on the pulse at the wrist, I satisfied myself that it was indeed the heart which I grasped. I then brought him to the king that he might behold and touch so extraordinary a thing, and that he might perceive, as I did, that unless when we touched the outer skin, or when he saw our fingers in the cavity, this young nobleman knew not that we touched the heart!" Other observations confirm this great authority, and the heart is declared insensible. And yet the opinions of mankind must not be lightly condemned. Not only does every emotion of the mind affect the heart, but every change in the condition of the body is attended with a corresponding change in the heart: motion during health—the influence of disease—every passing thought will influence it. Here is the distinction manifested. The sensibility of the skin is for a purpose, and so is the sensibility of the heart. Whilst the skin informs us of the qualities of the external world and guards us against injury from without, the heart, insensible to touch, is yet alive to every variation in the constitutional powers, and subject to change from every internal influence.

There is in the several organs of the body, as it were, a distinct life; that is, they possess sensibility, the grand endowment of life, necessary to their condition and adapted to their appropriate stimulus. The impressions made upon them will sometimes rouse them into

activity, or call muscles into action which are necessary to their functions or for their protection; and this oftentimes without reference to the mind at all, and consequently without our consciousness.

Perhaps we have the most agreeable example of this in the eye. That organ has been selected, in the Preliminary Discourse of the Objects and Pleasures of Science, as showing how mechanical advantage is taken in the arrangement of the muscles to produce velocity of movement in guarding the eye. But this fine mechanism would be lost if the excitement depended on our will,—if there were not a sensibility appropriate to the action, and an influence quicker than thought. It is not by feeling the pain of the offensive body, or by estimating its dangers and acting on the conviction, that we close the eye to avoid injuries. This would be an operation all too slow for the intended purpose; and therefore the muscles, possessing these extraordinary provisions, are put in relation with a sensibility more admirable still. So when a light foreign body touches the eyelashes, they give alarm, and cause a motion both of the eyelids and eyeball quicker than thought. The eyelashes, seated on the tender extremities of sensitive nerves, preserve the eye in two ways—by guarding its interior from the lateral light, and by exciting the motion of the eyelids, even before the offensive body can touch the eye's surface.

We may take another illustration to show how sensibility, one of the endowments of the living part, is adapted to the mechanical organization, and with an appropriation more admirable than the mechanism. When we speak of the sensibility of the skin, it is still possible to misconceive its nature, and to suppose it accident merely; but in the instance to be adduced, the sensibility is different, and it is put in connection with a hundred muscles; without this high and peculiar sensibility, and its multiplied relations to muscles, independent of volition, the mechanism we are about to describe would be quite useless.

The top of the windpipe is called the *larynx*, and consists of five elastic cartilages. These do not merely keep the sides of the windpipe apart, and the passage for the breath free, but they perform offices important to the economy both of body and mind; they are an

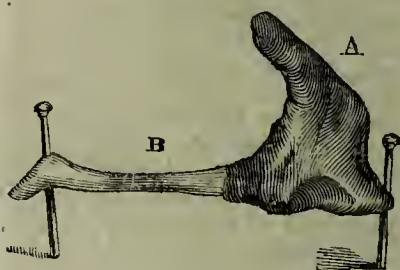
essential part of the instrument of voice; they, at the same time, guard the lungs from injury.

Fig. 24.



The *thyroid* cartilage is the largest of the cartilages of the larynx, it is that we feel projecting on the fore part of the throat, called the *pomum adami*, (A.) It is a protection to the fine apparatus behind it, and indeed this is the reason of its name, (*scutiform*, like a shield.) Within the thyroid stand the *arytenoid* cartilages, (B.) This cartilage is of an

Fig. 25.



irregular triangular form. It is socketed or articulated on the cartilage below, and is perfectly movable. To the corner which projects forwards the ligament (B) is fixed, and to its other sides five little muscles are attached; these muscles, by moving the cartilage, draw and vary the position of the ligament. It is these cartilages and this ligament, which, vibrating in the stream of air, give the tremor, and vocalize the breath; the tones so produced are articulated in speech.

This is a subject far from being exhausted in our philosophical works, and may call for observation afterwards; but at present we may look on these ligaments, not as the *cordæ vocales*, but

in another of their offices—forming the slit which opens and shuts in breathing, for the protection of the lungs. But here it is pertinent to remark, that in the structure of an animal body one organ is made subservient to several functions, without interference in the performance of any of them. This is especially true of the larynx. It is one of those uses only, and the least important, that we have at present to observe.

The ligaments being invested with the lining coat, or membrane of the wind-pipe, draw it into the form of a slit like the till of a shop counter, and this is the chink of the glottis (*rima glottidis*.) This slit opens and closes with every inspiration, moving as we see the nostrils do in breathing. But the most admirable thing of all is the acute sensibility given to this part, and to no other, so that the lightest husk, or seed, or smallest fly, drawn in with the breath, and touching the margin of the chink, is caught there by the rapid action of the muscles and consequent closing of the aperture. Now were the provision for the protection of the lungs to be only thus far perfect, there would be an effectual means of preventing the intrusion of foreign matter into the delicate cells of the lungs, but not for its expulsion from the entrance which it had reached. Accordingly, although the sensibility of the glottis is put in operation with the shutting of the chink, it also animates another class of muscles; viz. all those which, seated on the chest, compress it, and force out the air in coughing; and these combining in one powerful and simultaneous effort, whilst the glottis is closed, overcome that constriction, and propel the breath through the contracted pipe with an explosive force, which brushes off the offending body. There is one thing more, necessary to this most important though familiar action;—the lungs are never empty of air; in breathing we do not fully expel the air; if we did, there would be a period of danger occurring 17 times in a minute; for in the first part of each inspiration something might be drawn into the wind-pipe, which would suffocate. But by this provision of air retained in the lungs more than necessary to respiration, and which it is possible to expel by a more forcible expiration, there is always a possibility of coughing and expelling the offensive thing at any point of time in the act of inspiration.

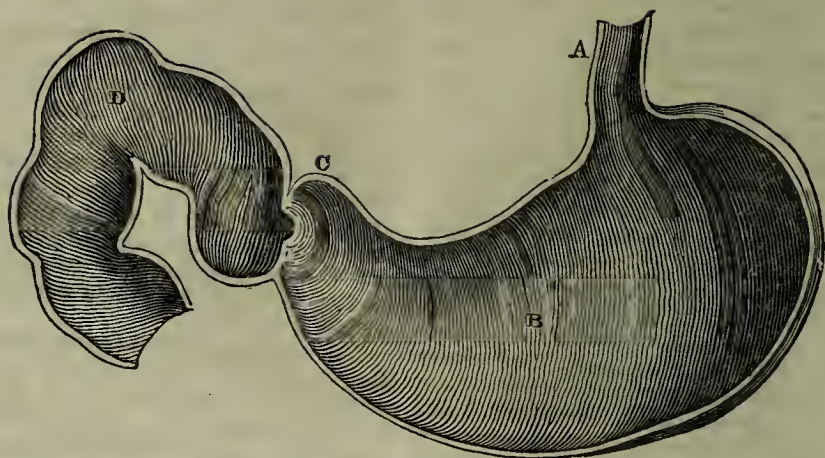
The sensibility seated in a spot of the throat so beneficently, does not extend into the wind-pipe; for we cannot more admire the perfect adaptation of this living property, than the circumstance of its never being bestowed in a superfluous degree, nor extended where it is not absolutely required. Just as the sensibility of the skin protects the parts beneath, so in the same manner does the sensibility of the top of the wind-pipe protect all the interior of the tube, and the lungs themselves, without the necessity of this property of irritability extending through the whole continuous surface.

The simple act of sneezing affords a very curious instance of the mutual adaptation of muscular activity and the governing sensibility. The sensation which gives rise to this convulsive act, is seated in the membrane of the interior of the nostrils, and we are not surprised with the difference of sensation from that in the throat which excites coughing. But is it not a very curious thing to find some twenty muscles thrown out of the action excited by irritation of the nose; and as many excited which were not in the class of those influenced in coughing; and for the very obvious purpose of shutting the passage by the mouth, or at least forcibly driving the air through the nostrils? No act of the will could so successfully propel the air through the nose in such a way as to remove the offensive and irritating particles from the membrane of the nose, and clear those passages.

These last examples of an appropriate sensibility might introduce us to an acquaintance with those internal sensibilities which govern the actions of parts quite removed from the influence of the will; but the description of them may be deemed unnecessary. We shall just hint at the guard which nature has placed on the lower orifice of the stomach, to check the passage which the appetites of hunger and thirst may have given at the upper orifice (A) to aliments, not easy of digestion. This lower orifice (C) is encircled with a muscular ring; the ring is in the keeping of a watchful guard. If we are employing the language of metaphor, it is of ancient use. The Greeks called this orifice *pylorus*, which signifies a porter,*

* The upper orifice was called by them *œsophagus*, as it were the *purveyor*, from two words signifying to bring food.

Fig. 26.



and his office is this.—When the stomach has received the food, it lies towards the left extremity, or is slightly agitated there. When the digestive process is accomplished, the stomach urges the food towards the lower orifice. If the matter be bland and natural it passes, and no sensation is experienced. But if crude and undigested matter be presented, opposition is offered to its passage, and a contention is begun which happily terminates in the food being thrown again to the left extremity of the stomach, to be submitted to a more perfect operation of the digestive powers seated there. It is during this unnatural retrograde movement of the food, that men are made sensible of having a stomach. Yet the sensations, how unpleasant soever, are not to be regarded as a punishment, but rather as a call on reason to aid the instinctive powers, and to guard against disease, by preventing impure matter from being admitted into the portion of the intestinal canal, which absorbs, and would thus carry those impurities into the blood to engender disease.

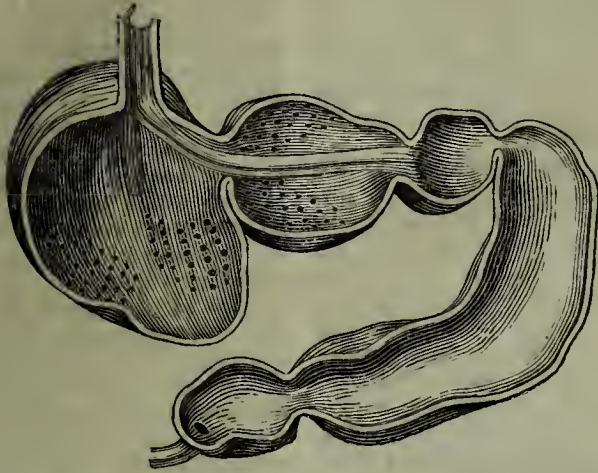
Such are a few examples of the variety in the sensibilities of the animal frame; guarding us against external influences when they would threaten destruction to the framework, and adjusting the operations of internal parts too complicated and too remotely situated for the superintendence of reason.

Medical authors, without being empirics, do, notwithstanding, take great advantage of our ignorance. We can all of us take warning from the sensations experienced in the process of

digestion, and there can be no harm in giving every man a confidence in the sensibility of his stomach, and in its indications of healthy or disturbed functions. We have the best proof of what we wish to inculcate in the action of the ruminating stomach. A cow swallows the gross herbage, and fills its large first stomach. When it chews the cud, the stomach, by its action, rolls up the grass into distinct pellets, or balls, with as much regard to the office of its being rejected into the mouth, as we do in masticating for swallowing. When the ball is brought into the mouth and chewed, it is again swallowed; but in descending into the lower part of the gullet a muscle draws close the aperture by which it passed into the large stomach in the first instance, and it is now ushered into a second stomach, and so successively onwards to that stomach in which the digestion is performed. The curious muscular apparatus by which this is accomplished needs not be described; but surely the sensibility which directs it, which, kept apart altogether from the will, is yet, in its results, so like the operations of reason, presents a subject of just admiration.

The elastic structure of the camel's foot; the provision around its eyes for ridding them of offensive particles; the power of closing its nostrils against the clouds of sand; and its endurance of fatigue—would not enable it to pass the desert, unless there were provisions for the lodgment of water in its stomach, and unless this apparatus were animated by peculiar sensibilities; for there are muscles to retain the fluid in the cells of

Fig. 27.



its stomach, only permitting it to ooze out according to the necessities of the animal; and there is a muscle, represented in the *fig.* above, which pulls up the one or the other of the orifices of the different stomachs to receive the food from the lower end of the gullet, according to its condition, whether to be deposited merely as in a store, or to be submitted to the operation of digestion.

The surprising thing in all this, is not so much the mechanical provision as the governing sensibility. What, for example, should in the first place impel the grosser food, when collected, into the first stomach? What should, in the next place, and after rumination and mastication in the mouth, carry it into the third stomach; since water is carried into neither of these, but into the cells of the second stomach?

Yet, after all, this only brings us back to a sense of the operations of our own bodies. The act of swallowing, the propulsion of the food into the gullet, and the temporary closing of the wind-pipe at such a time, is just as surprising. This latter operation is never deranged but by the interference of the will. If the individual attempts to speak, that is, to govern these parts by the will, when they should be left to these instinctive operations; or if terror, or some such mental excitement, prevail at the moment of swallowing, then the morsel may stick in the throat.

All this shows how perfect the operations of nature are, and how well it is provided that the vital motions should be withdrawn from the control of reason, and even of volition, and sub-

jected to a more uniform and certain law.

But the point to which we would carry the reader is this, that though there are the proper sensibilities of the body, with reference to perception or consciousness, yet there are others no less curious, which control the internal operations of the economy; and that the mechanical provisions are but a type of what is promised to him who will look into the sensibilities of the body for the proof of power and contrivance.

Now the human stomach, though not so complicated in its apparatus of macerating and digesting vats, is possessed of a no less wonderful degree of governing sensibility, which may be trusted as surely as the most skilful physiologist.

We are told that we must not drink at meals, lest the fluid interfere with the operation of digestion; of this there need be no apprehension. The stomach separates and lets off with the most curious skill, all superfluous fluid through its orifice, while it retains the matter fit for digestion. It retains it in its left extremity, permitting the fluid to pass into the intestines, there to supply the other wants of the system no less important than the digestion. The veterinary professor Coleman, ascertained that a pail of water passed through the stomach and intestines of a horse, at the rate of ten feet in the minute, until it reached the cæcum. Drinking at a stated period after meals, say an hour, is at variance with both appetite and reason. The digestion is then effectually interfered with; for what was solid has become a fluid, (the *chyme*.)

This fluid is already in part assimilated; it has undergone the first of those changes which fit it ultimately to be the living blood; and the drink mixing with this chyme in the inferior extremity of the stomach, or first intestine, must produce disturbance, and interrupt the work of assimilation.

Looking in this manner upon the very extraordinary properties of the stomach, we perceive how natural it was for physicians to give a name to the sensibility of which we have been speaking. The *Archeus* of Vanhelmont, the *Anima* of Stahl, were the terms used to designate this nature, principle, or faculty, subordinate to, and distinct from perception;—a notion entertained, and more or less distinctly hinted at, by philosophers from Pythagoras to John Hunter.

A modern philosopher,* of whom, in this instance, it would be difficult to say whether he be serious or playful, with some plausibility, however, asserts that it might be possible to carry on the business of life without pain. If animals can be free from it an hour, they might enjoy a perpetual exemption from it. Animals might be constantly in a state of enjoyment; instead of pain, they might feel a diminution of pleasure, and might thus be prompted to seek that which is necessary to their existence.

In the lower creatures, governed by instinct, there may be, for ought we know, some such condition of existence. But the complexity and delicacy of the human frame is necessary for sustaining those powers or attributes which are in correspondence with superior intelligence; since they are not in relation to the mind alone, but intermediate between it and the external material world. Grant that vision is necessary to the developement of thought, the organ of it must be formed with relation to light. Speech, so necessary to the developement of the reasoning faculties, implies a complex and exceedingly delicate organ, to play on the atmosphere around us. It is not to the mind, that the various organizations are wanted, but to its condition in relation to a material world.

The necessity of this delicate structure being admitted, it must be preserved by the modifications of sensibility, which shall either instinctively protect the parts, or rouse us into powerful

and instantaneous activity. Could the eye guard itself, unless it possessed sensibility greater than the skin? Could it guard itself, unless this sensibility were in consent with an apparatus which acted as quick as thought? Could we, by the mere influence of pleasure, or by any cessation or variation of pleasurable feelings, be made alive to those injuries which might reach the lungs by substances being carried in with the air we breathe? Is there anything but the sense which gives rise to the apprehension of suffocation, that would produce the instant and sudden effort which could guard the throat from the intrusion of what was offensive or injurious. Pleasure is at the best a poor motive to exertion, and rather induces to languor and indulgence, and at length indifference. To say that animals might be continually in a state of enjoyment, and that when urged by the necessities of nature, such as thirst, hunger, and weariness, they might only feel a diminution of pleasure, is not only to alter man's nature, but external nature also; for, whilst there are earth, rocks, woods, and water for our theatre of existence, the textures of our bodies must be exposed to injuries, from which they can only be protected by a sensibility adapted to each part, and capable of rousing us to the most animated exertions. Take away pain, and take also away the material world, by which we are continually threatened with injury, and what, after all, is this, but imagining a future state of existence, instead of that in which mind and matter are combined? If all were smooth in our path, if there were neither rugged places nor accidental opposition, whence should we derive those affections of our minds, which we call enterprise, fortitude, and patience?

Independent of pain, which protects us more powerfully than a shield, there is inherent in us, and for a similar purpose, an innate horror of death. "And what thinkest thou (said Socrates to Aristodemus) of this continual love of life, this dread of dissolution, which takes possession of us from the moment that we are conscious of existence?" "I think of it, (answered he,) as the means employed by the same great and wise artist, deliberately determined to preserve what he has made."

The reader will no doubt here observe the distinction. We have experience of pain from injuries, and learn to

* Hume,

avoid them ; but we can have no experience of death, and therefore the Author of our being has implanted in us an innate horror at dissolution ; and we may see this principle extended through the whole of animated nature. Where it is possible to be taught by experience, we are left to profit by it, but where we can have none, feelings are engendered without it. And this is all that was necessary to show how the life is guarded ; sometimes by mechanical strength, as in the skull ; sometimes by acute sensation, as in the skin and in the eye ; sometimes by innate affections of the mind, as in the horror of death, which will prevail as the voice of nature, when we can no longer profit by experience.

But the highest proof of benevolence is this, that we have the chiefest source of happiness in ourselves. Every creature has pleasure in the mere exercise of his body, as well as in the languor and repose that follow exertion ; but these conditions are so balanced, that we are impelled to change, and every change is an additional source of enjoyment. What is apparent in the body, is true of the mind also. The great source of happiness is to be found in the exercise of talents, and perhaps the greatest of all is when the ingenuity of the mind is exercised in the dexterous employment of the hands. Idle men do not know what is meant here ; but nature has implanted in us this stimulus to exertion, that she has given to the ingenious artist—the man who invents, and with his hands creates, a source of delight, perhaps greater, certainly more uninterrupted, than belongs to the possession of higher intellectual powers, and far beyond any that falls to the lot of the minion of fortune.

We believe that every thinking person may have wherewithal in his own sphere to tutor him, and bring him to the temper of mind and belief which we would inculcate. Yet there is something peculiarly appropriate in the study of our own bodies. In chemistry we are so much the agents as to forget the law, and the law itself seems at least to intermit. But in the changes wrought in the animal frame, the directing power is uniform in its influence, and holds all in harmony of action.

We now learn without difficulty and without mystery, what is meant by organic and animal sensibility. The first is that condition of the living organ,

which makes it sensible of an impression, on which it reacts and performs its functions. It appears from what has preceded, that this sensibility may cause the blowing of a flower, or the motion of a heart. The animal sensibility is indeed an improper term, because it would seem to imply that its opposite, organic sensibility, was not also animal ; but it means that impression which is referred to the sensorium ; where, (when action is excited,) perception and the effort of the will are intermediate agents between the sensation and the action or motion.

We may sum up the inquiry into sensibility and motion thus :—

1. The peculiar distinction of a living animal is, that its minute particles are undergoing a continual change or revolution under the influence of life. Philosophers have applied no term to these motions.

2. An organ possessed of an appropriate muscular texture, and of sensibility in accordance with the moving instrument, as the heart, or the stomach, has the power of action without reference to the mind. The term *automatic*, sometimes given to those motions, conveys a wrong idea of the source of motion, as if, instead of being a living power, it were consequent upon some elastic or mechanical property.

3. There are sensibilities bestowed on certain organs, and holding a control over a number of muscles, which combine them in action in a manner greatly resembling the influence of the mind upon the body, yet independent of the mind ; as the sensibility which combines the muscles in breathing.

4. In the last instance a large class of muscles were combined without volition. But the whole animal fabric may be so employed ; as in the instinctive operations of animals, where there is an impulse to certain actions not accompanied by intelligence.

5. A motive must exist before there are voluntary actions, and hence philosophers have supposed that there can be nothing but instinctive actions in a new-born child. But we must distinguish here what are perfect at first, and what are imperfect and irregular, and become perfect by use and the direction of the will. The act of swallowing is perfect from the beginning. The motions of the legs and arms, and the sounds of the voice are irregular and weak, and imperfectly directed. It is the latter

which improve with the mind. From not knowing the internal structure, and the arrangement of the nerves, philosophers, as Hartley, supposed, that an instinctive motion, such as swallowing, may become a voluntary act. Volition in the act of swallowing, consists merely in putting the morsel within the instinctive grasp of the fauces, when a series of involuntary actions commence, over which we have no more control in mature age, than in the earliest infancy. Swallowing is not a voluntary action, and the thrusting the morsel back with the tongue, is like putting the cup to the lip. It is the preparation for the act of swallowing that is voluntary, but over the act itself, we have no control.

It is an error to suppose that all muscular actions are, in the first instance, involuntary, and that over some of them we acquire a voluntary power. The power of volition over the muscles of the body, is provided for by appropriate nerves, and no apparatus which is not supplied with that particular class of nerves, can ever, by any exercise or study, become subject to volition. A child's face has a great deal of motion in it, very diverting from its resemblance to expression, before there can be any real motive to the action. It will crow, and make strange sounds, before there is an attempt at speech. But this gradual developement of intelligence and acquisition of power ought not to be called the will attaining influence over involuntary muscles; since, in fact, the apparatus of nerves and muscles is prepared and waits for the direction of the mind with so perfect a readiness, as to fall into action and just combination, before that condition, or affection of the mind which should precede the action, takes place. A child smiles before any thing incongruous can enter the mind, before even pleasure can be supposed a condition of the mind. Indeed, the smile on an infant's face is first perceived in sleep.

6. All the motions enumerated above, are spontaneous motions belonging to the internal economy; but the external relations of the animal, the necessity of escaping from injury, or warding off violence, require a sensibility suited to those outward impressions, and an activity consequent on volition. Nothing less than perceptions of the mind, and voluntary acts, suited to a thousand circumstances of relation,

could preserve the higher classes of animals, and man above all others, from destruction.

All these provisions proceed from an arrangement of nerves and muscles. The mechanical adjustment of the muscles and tendons, is perfect according to the principles of mechanics. The muscles themselves possess a different property; they are irritable parts; motion originates in them. This living property of contraction is admirably suited, in each particular muscle, to the office it has to perform. In some it is suitable that the muscles should act as rapidly as the bowstring on the arrow; in others the action is slow and regular; in others it is irregular, and after long intervals, according as the functions to which they are subservient require. The motions of the limbs, the motions of the eye, those of the heart and arteries, stomach and bowels, are all different. This appropriation of action is not in the muscles themselves, but as they stand in relation to the nervous system, and the sensibilities which impel them.

We hope, then, by the course we have taken, that we have carried the reader to a higher sense of the perfection of the animal structure. We first drew him to observe provisions in the strengthening of the bones, the adjustment of their extremities to the joints, the course of the tendons, and other such mechanical appliances, proving to him the existence of intention in the formation of the solid fabric of the body. We have then explained how that motion is produced which was at all times familiar to him, but even the immediate causes of which he did not comprehend. We have, in the last place, shown him that under the term life he has a still more admirable subject of contemplation in the adjustment of those living properties; in the sensibilities differing not so much in degree as in kind; and in their appropriation, both to the operations of the internal economy, and to the relations external, and necessary to safety.

It is not possible to contemplate these things without having the full proof before us of the power of the Creator in forming and sustaining the animal body. As a man with *gutta serena* may turn his eyes to the sun, and feel no influence of light; so may the understanding be blind to these proofs; and we may say, with the celebrated

Dr. Hunter, that he who can contemplate them without enthusiasm, must labour under a dead palsy in some part of his mind, and we must pity him as unfortunate.

CHAPTER IV.

Of the Changes in the Material of the Animal Body during Life.

WE have seen the motions performed in the animal body through the actions of the muscles, and the play of the mechanical parts, and we have had occasion to reflect on the action of the heart, and the motion of the blood in the circulation; but these are as nothing, compared with the interest of our present subject—the changes going forward in the solid material of the frame. Is it not surprising that the individual who retains every peculiarity of body and of mind, whose features, whose gait and mode of action, whose voice, gestures, and complexion we are ready to attest as the very proof of personality, should in the course of a few days change every particle of his solid fabric?—that he whom we suppose we saw, is, as far as his body is concerned, a perfectly different person from him we now see? That the fluids may change we are ready to allow, but that the solids are thus ever shifting seems at first improbable. And yet, if there be any thing firmly established in physiology, if there be truth in the science at all, this fact is incontrovertible.

There is nothing like this in inanimate nature. It is beautiful to see the shooting of a crystal;—to note, first, the formation of integrant particles from their elements in solution, and these, assuming a regular form under the influence of attraction or crystalline polarity, producing a determinate shape; but the form is permanent. In the different processes of elective attraction, and in fermentation, we perceive a commotion, but in a little time the products are formed, and the particles are at rest. There is in these instances nothing like the revolutions of the living animal substance, where the material is alternately arranged and decomposed. The end of this is, that the machinery of the body is ever new, and possesses a property within itself of mending that which was broken, of throwing off that which was useless, and of building up that which was in-

secure and weak; of repelling disease, or of controlling it, and substituting what is healthful, for that which is morbid. The whole animal machinery we have seen to be a thing fragile and exposed to injury; without this continual change of material, and this new modelling of that material, our lives would be more precarious; the texture of our bodies would be spoiled like some fine piece of mechanism which had stopped, and no workman would have science sufficient to reconstruct it. But by this process, the minute particles of the body die successively; not as in the final death of the whole body, but part by part is deprived of its vitality, and taken away into the general circulation, whilst new parts are endowed with the property of life, and are built up in their place. By this revolution, we see nature, instead of having to establish a new mode of action for every casualty, heals all wounds, unites all broken bones, throws off all morbid parts by the continuance of its usual operations; and the surgeon who is modest in his calling, has nothing to do but to watch, lest ignorance or prejudice interfere with the process of nature. This property of the living body to restore itself when deranged, or to heal itself when broken or torn, is an action which so frequently assumes the appearance of reason, as if it were adapting itself to the particular occasion, that even the last great luminary in this science, Mr. John Hunter, speaks of parts of the body, as “conscious of their imperfection,” and “acting from the stimulus of necessity,” thus giving the properties of mind to the body, as the only explanation of phenomena so wonderful.

We make a moderate assumption, when we declare these changes to be under the guidance of the living principle. In a seed, or a nut, or an egg, we know that there is life, and from the length of time that these bodies will remain without change, we are forced to acknowledge that this life is stationary or dormant, and limited to the counteraction of putrefaction or chemical decomposition; but no sooner does this principle become active, than a series of intestinal or internal changes are commenced, which are regularly progressive, without a moment's interruption, while life continues.

That principle which may continue an indefinite number of days, months, or years, producing no change in all this

time, begins at once to exhibit its influence, builds up the individual body, regulates the actions of secretion and absorption; and, by its operation upon the material of the frame, stamps it with external marks of infancy, maturity, and age.

But let us examine the proofs of this universal change in the material of the body. It is not very long since a bone was supposed to be a concrete juice, and that the liquid parts were converted into solids, as we see mortar or Paris plaster from fluid assuming a solid form. But the anatomist began to observe, that the bones were porous; that these pores admitted membranes and vessels; and some went so far before their brethren, as to assert that they saw arteries, veins, lymphatics, and nerves going into the bone; in short, the opinion gradually grew stronger, that they were living parts, and subject to all the changes to which the softer parts of the living body were liable. An accident gave admirable proof of this. It was found that the bones of pigs, fed with the refuse of the dyer's vats, in which madder was contained, became tinged of a beautiful red colour. It was this fact which ingenious physiologists made use of, and which enabled them to demonstrate the rapidity with which the old bone was carried away, and new bone substituted. The physiologist observed, that if he threw a bone into the fire, what is called the animal part was burned and dissipated, but there remained, imperishable by this process, a mass of earth, which proved to be the phosphate of lime. He thought of varying his experiment, and put the bone into acid, which dissolved that phosphate of lime, and left the bone to all outward appearance as before. It had its form, its membranes, its vessels, but when pressed it proved to be soft and pliant; the phosphate of lime having been dissolved and extracted, it was no longer capable of the office of a bone, to bear the weight and motions of the body. When the experiments with madder were resumed, it appeared, that when this earth of bone was about to be secreted from the circulating vessels, and deposited in the membranes of the bone, it met with the colouring particles of the madder in the blood; and, as the chemist would explain, the madder and the phosphate of lime were precipitated, and filled all the interstices of the membranes and vessels.

We shall not stop here to inquire into the admirable manner in which this hardening material of bone is deposited for the purposes of strength. It is only the change upon the material which we have now to contemplate.

If this earth of bone, so coloured, had been deposited for a permanency, and built into these cells and crevices, like brick and mortar, the colour would remain; but, however deeply the bones of an animal may be tinged in this manner, the colour is not permanent, unless the animal continue to be fed with the madder. If its food be pure of the madder, even for a few weeks, and if after this the animal be killed, its bones are white, that is to say, the old particles of phosphate of lime are carried away by absorption, and with them the colouring material; and that newer bone which is deposited by the arteries is untinged and pure, having no colouring material to attract.

It is unnecessary to follow out those curious experiments by which the physiologist has shown the rapidity of the formation of a new bone around the broken end of an old one, and the deep tinge such new bone takes, compared with the fainter colour of that which had been perfect, previous to the feeding with madder; the manner in which, by feeding the animal alternately with madder and without it, he contrives to exhibit different coloured layers in the growing bone. It is sufficient for our purpose, to know that the densest part of the animal frame is subject to change, like the most delicate texture of the body, and that the only means of arresting the motion, is to deprive it of life: if a part of a bone be killed by the application of a cautery, that moment it becomes permanent, and is subject to no change, whilst all the parts around it are undergoing their revolutions.

The bones of the legs and thighs, which suffer the fatigue of motion, and which support the weight of the body, without diminishing in their length, or altering in the slightest measurable degree their proper form, are nevertheless undergoing an operation of repair, in which the old particles are withdrawn, whilst new ones replace them. We see with what care the walls of a house are shored up to admit of repair—how carefully the workman must estimate the strength of his pillars and beams—how nicely he must hammer in his wedges, that every interstice may be filled, and no

strain permitted; and if this operation fail in the slightest degree, it is attended with a rent of the wall from top to bottom. We say, then, that by the very awkwardness of this process, in which, after all, there is danger of the whole fabric tumbling about the workmen, we are called upon to admire how the solid pillars in our own frame are a thousand times renewed, whilst the plan of the original fabric is followed to the utmost nicety in their restoration. And if it deviate at all, it is only in a manner the more to surprise us, since, on examination, it will be discovered to result from an adaptation of the strength of material to some new circumstance, the increasing weight it has to support, or the jar that it is subject to, from the change in the activity or exercise of the body.

There is a disease of the bone which illustrates this in a surprising manner, and proves to us, that however diseased and monstrous in its shape the bone may be, yet there is a natural law operating, which by its prevalence will overcome the morbid action, and from a shapeless mass restore the bone to its natural condition.

This disease is called *necrosis*, which word signifies the *death* of the bone merely; but it is death in very peculiar circumstances; a new bone is formed around the old one; a large and clumsy cylinder is fashioned of the earth of bone; in the hollow of which the shaft of the old bone is contained. After a long time the old bone comes out through this new case, and with the aid of the surgeon, it is altogether withdrawn from the limb. During all this process the patient is capable of supporting his weight upon that limb, so that it resembles on a large scale that change which we have described as going continually on in the molecules of the bone; a new part is substituted, and the old taken away.

If workmen were to take away a pillar in the following manner, their work would resemble the process of necrosis: first, they must rear a hollow cylinder around the old pillar, resting on the plinth and base, and extending to the capital, and having secured the union of the cylinder at top and bottom to the extremities of the pillar, they must take away the shaft, or middle piece, of the old pillar by perforating the new cylinder.

The reader may easily imagine that

when this process is completed in a man's limb it will be as clumsy as the leg of an elephant, large, firm, and shapeless; but the extraordinary circumstance is still to be described.—This new bone is gradually diminished in its exterior surface, and its hollow filled up, and thus, by a change scarcely perceptible, it resumes the form and dimensions of the original bone; and, after a time, the anatomist might examine this limb and find neither in the articulating surfaces, nor in the spines and ridges, nor in the points of attachment for ligaments and muscles any thing to indicate the extraordinary revolution that had taken place.

What explanation have we to give of this change? There can be no doubt that the material is not the same; for we have the old bone in our hand, and the man is walking upon a new bone. Yet extraordinary, then, as this appears, it is not more inexplicable than the common phenomenon of the growth of an infant to maturity. There is a living principle which is permanent while the material changes; and this principle attracts and arranges, dissolves and throws off successive portions of the solids. There is a law influencing this living principle, which, in its operation on the material, shapes and limits the growth of every part, and carries it through a regular series of changes, in which its form and aptness for its office are preserved, whilst the material alone is altered.

The influence of disease will for a time disorder this modelling process and produce tumours and distortions; but when at length the healthy action, that is the natural action, prevails, these incumbrances are carried away, and the fair proportions of the fabric are restored.

It is very pleasing to observe the different means employed where a slight change of circumstances demands it. This earth of bone—the phosphate of lime, is changing continually; but the teeth admit of no change; they consist of earth too—the phosphate, carbonate, and fluuate of lime. Bodies calculated for such violent attrition, and with a surface so hard as to strike fire with steel, would be ill accommodated with such a property of changing as we have seen in the bones. They must therefore fall out and be succeeded by new ones; and this process, familiar as it may be, is

very curious when philosophically considered.

There are no teeth whilst yet the infant is at the breast; and when they rise they are attended with new appetites, and a necessity for change of food. When perfected they form a range of teeth, neat and small, adapted to the child's jaws and the size of its bones. Were they to grow at once, or to fall out at once, it would prove a disturbance to the act of eating. They fall in succession; their fangs are absorbed, they are loose and jangling, and are easily extracted. But now comes the question, why are these teeth of the infant old at six years? Why are those that are to succeed and be stationary for a series of years, to germinate and grow at the appointed time like the buds in the axilla of a leaf? And when fully formed, why do they remain perfect for sixty years instead of six; at the end of which term the first set were old and decayed? No difference can be observed in the material of the teeth of the first or second set. The one will be as perfect as the other after remaining a hundred years in a charnel house. Can any one refuse his belief, then, when he sees so accurate a mechanical adaptation of the teeth to their places and their offices; can he, we say, refuse assent to this also, that there is a law impressed—a property by which the milk teeth shall fail and be discharged from the jaw in six years, whilst the others will last the natural life of the adult, if not injured by accidents to which all parts are subject? This is not the only instance in which parts of the body lie dormant for a term of years, and are at a particular period of life developed and perfected—and which have, we may say, their time of infancy, perfection, and decay, whilst yet there is no material deterioration observable in the general frame.

We are thus brought to the consideration of a question which has not yet been fairly stated.

Those who say that life results from structure, and that the material is the ruling part, bid us look to the contrast of youth and age. The activity of limb and buoyancy of spirit they consider as a necessary consequence of the newness and perfection of organization in youth. On the other hand, a ruined tower, unroofed, and exposed to be broken up by alternation of frost and heat, dryness and moisture, wedged by

the roots of ivy, and tottering to its fall, they compare with old age—with the shrunk limbs, tottering gait, shrivelled face, and scattered grey hair of the old.

But in all this there is not a word of truth. Whilst there is life and circulation there is change of the material of the frame, (and there is a sign of this if a broken bone unites or a wound heals.) Ascribe the distinction to the rapidity of change, to the velocity of circulation, or to the more or less energy of action; but with the antiquity of the material it can have nothing to do. The roundness and fulness of flesh, the smoothness, transparency, and colour of the cheek, belong to youth, as characteristic of the time of life, not as a necessary quality of the material! Is there a physiognomy in all nature—among birds and beasts, and insects and flowers—and shall man alone have no indication of his condition in the outward form and character?

The distinctions in the body, apparent in the stages of life, have a deeper source than the accidental effects of the deterioration of the material of the frame. The same changes which are wrought on the structure of the body in youth and in the spring of life are going on in the last term of life; but the fabric is rebuilt on a different plan. The law of the formation is still inherent in the life which has hurried the material of the body through a succession of changes; and each stage, from the embryo to the foetus, the foetus to the child, from that to adolescence, to maturity, and to the condition of old age, has its outward form, as indicative of internal qualities, but not of the perfection or imperfection of the gross material. We might as well consider the difference in the term of life of the annual or biennial plant as compared with the oak, or the ephemeral fly as compared with the bird that hawks at it, to be in the qualities of the matter which forms them, as that the outward characters of the different stages of human life arose from the perfection or imperfection of the material of the body. Not only has every creature its appointed term of life, but we have shown that parts of the human body do not, in this respect, bear a relation to the whole; organs are changed and disappear; others, in the mean time, at their regulated period, shoot to perfection, and again decay before the failure of the body. What can more distinctly

show that it is the principle of life that directs all ; and that on it the law is imprinted which orders our formation, and all the revolutions we undergo. The material of the body, solid and fluid, is moved by this influence, and varies every day, part by part dying every hour, and renewed, until the series of its changes on the gross material of the body is accomplished in an entire and final separation.

The grand phenomena of nature make powerful impression on our imagination, and we acknowledge them to be under the guidance of Providence ; but it is more pleasing, more agreeable to our self-importance, it gives us more confidence in that Providence, to discover that the minutest changes in nature are equally His care, and that "all things do homage."

Although it be true that every thing in nature, being philosophically contemplated, will lead to the same conclusions, yet the occurrences around us steal so imperceptibly on our observation, all the objects of nature, or at least vegetable and animal productions, grow up by so slow a process by our side, that we do not consider them at all in the same way as we should do if they started suddenly upon our vision.

It is this familiarity with the qualities of a living body, and a habit of seeing without reflection, which has made it necessary to carry the reader through so long a course of observation and reasoning to excite attention to the admirable structure of his own frame, and its adaptation to the earth we inhabit—to perceive that every thing is formed with a strict relation to the human faculties and organs, to extend our dominion and to multiply our sources of enjoyment. It is by seeing the plan of Providence in the establishment of relations between the condition of our being and the material world, that we learn to comprehend that unity of design in the creation in which we form so great a part.

This exaltation of our nature is not like the influence of pride or common ambition. We may use the words of Socrates to his scholar, who saw in the contemplation of nature only a proof of his own insignificance, and concluded "that the gods had no need of him," which drew this answer from the sage: "The greater the munificence they have shown in the care of thee, so much the more honour and service thou owest them!"

the first of the year 1781, the British army, under the command of General Cornwallis, was defeated by the Continental Army, under the command of General Washington, at the Battle of the Clouds. This battle was a decisive victory for the Continental Army, and it marked the end of the British occupation of the city of York. The British army was forced to evacuate the city and to retreat to the coast. The Continental Army followed them and defeated them at the Battle of the Clouds. This battle was a decisive victory for the Continental Army, and it marked the end of the British occupation of the city of York. The British army was forced to evacuate the city and to retreat to the coast. The Continental Army followed them and defeated them at the Battle of the Clouds.

ANIMAL PHYSIOLOGY.

THE term Physiology, derived from two Greek words, one of which signifies *nature*, and the other *an account of*, appears to have been originally employed to designate a discourse concerning natural objects in general. For a long time past, however, this word has been restricted to a science which comprehends only a particular class of beings, distinguished by peculiar and very important characters. *Organization* confers on the bodies which possess it properties sufficiently distinctive to form the basis of a division of all the objects in nature into two great classes, namely, the inorganic and the organic.

In general, inorganic bodies possess no determinate structure. In some few, indeed, as in crystals, there is a definite and uniform arrangement of the component particles: but, even in these, as well as in inorganic bodies generally, these particles are merely in a state of aggregation, without mutual relation or dependence; the motions of their entire mass are regulated by certain physical laws, the operation of which is fixed and invariable; and the motions of the integrant parts, and all the results of such motions, are equally determinate, while they are ascertained, or ascertainable, by direct experiment. The science which treats of this immense class of bodies, commonly termed Natural Philosophy, receives, in its primary divisions, different names, according to the kind of properties which it is its object to investigate. Thus, the science, which has for its subject quantity in general, is termed Mathematics; figure, Geometry; motion, that is, motion of entire masses, Dynamics: while that which investigates the motion of the integrant particles of masses, and the results of such motion, is denominated Chemistry.

Organized beings possess certain properties in common with inorganic bodies; but to these others are super-added, by which they are distinguished,

and which modify the first in a very wonderful manner, and to a very extraordinary extent. The sciences which treat of organized beings are two only: one has for its subject their structure, the other their functions: the first is termed Anatomy, the second, Physiology.

As far as can be determined by observation, organization has an inseparable relation to life, and life to organization. We see life only in organized bodies: we see organization only in living beings. That peculiar series of phenomena which is exhibited by organization when in action, that is, by living beings, constitutes the subject of Physiology. Physiology, then, is the science which investigates the functions of living beings: it is the doctrine, the science of life.

Who has not put to himself the question, What is life? Who would not receive a clear and just solution of the inquiry with a feeling of interest far beyond that afforded by the successful result of ordinary scientific investigation? We know the mechanism by which life acts: we *feel* its result. We see that that mechanism is so delicate, so complicated, so fragile, so easily set wrong, while our own interest is so deep that it should go well, and permanently well, that the exquisiteness of adjustment, the skill of contrivance, the completeness with which the intended result is secured, all subjects of distinct and interesting investigation, only increase the earnestness of our wish, that we could see beyond the mechanism, and understand that which it is permitted us to know only by consciousness. In this inquiry, we cannot forget that we ourselves are the subjects of the investigation, and that all we have, and are, and hope, are involved in the mystery; and the more we pursue the inquiry, the deeper we feel that there are few subjects which the human mind can

study which have a greater tendency to excite its wonder, to fill it with admiration, to penetrate it with gratitude. We do not commonly consider *how much* is given us in life: the daily enjoyment of the boon, renders us insensible of the variety and plenitude of its richness: we become more sensible of it when we contemplate the number of tissues that have been formed; the number of properties that are attached to each; the number of organs that are constituted by their aggregation and arrangement; the number of functions that are exercised by those organs; and the number of adjustments by which all are combined and harmonized, and made effectual to the production of one grand result: it is then we perceive how many things must exist, how many relations must be established, how many actions must be performed, how many combinations of actions must be secured, before there can be sensation, and motion, and thought, and happiness.

Physiologists of the highest distinction have spoken of life without reserve or explanation, as a principle or a power; a real and distinct agent, upon which the various phenomena of life depend. But life, as far as we affix any *scientific* meaning to the word, is a peculiar mode of being, in which a certain series of phenomena are observed to take place; these phenomena are never found associated with any other conditions, but that one to the designation of which the term life is appropriated: hence we use this word, merely as the short expression by which this peculiar state of being, or the associated phenomena which constitute it, are denoted. What life is, independently of this series of phenomena, we are wholly ignorant, as we are of everything but appearances in relation to every object in nature.

When these signs of life are carefully considered, it will be found that they are reducible to five, or that there are five properties which are peculiar to living beings, and by which therefore they are distinguished. Of these, the first is the property they possess of resisting, within certain limits, the operation of the ordinary laws of matter. Physical agents exert over inorganic bodies a constant and irresistible influence. Air, moisture, heat, produce, in all such bodies, incessant changes, subverting the closest union between their integrant particles, and forming

them into combinations entirely new. If a living being be brought under the influence of these agents, it is found capable of resisting such changes within a very considerable range, and it retains this power as long as it continues to be a living being. Thus the living body is not decomposed under degrees of temperature and moisture, which begin to resolve it into its primitive elements the moment it is dead. There is a certain temperature, different in different cases, at which the functions of the economy are performed in the best manner, and all living beings have the power of preserving that temperature, within a very considerable range, whatever may be the degree of heat or cold of the medium that surrounds them. The heat of a tree examined by Mr. Hunter was found to be always several degrees *above* that of the atmosphere when the atmospheric temperature was below 56° Fahrenheit; but it was always several degrees *below* it when the weather was warmer. The sap taken from the tree was found to freeze at 32°; while in the tree, it would not freeze below 47°. But animals exhibit the most surprising power of resisting the different degrees of heat or cold of the surrounding medium. The power of the superior animals, and especially of man, to resist high degrees of temperature, at first discovered by accident, and afterwards made the subject of direct experiment, is very extraordinary. In the year 1760, at Rochefoucault, Messieurs du Hamel and Tillet, having occasion to use a large public oven on the same day in which bread had been baked in it, wished to ascertain with precision its degree of temperature. This they endeavoured to accomplish by introducing a thermometer into the oven at the end of a shovel. On being withdrawn, the thermometer indicated a degree of heat considerably above that of boiling water; but M. Tillet, convinced that the thermometer had fallen several degrees on approaching the mouth of the oven, and appearing to be at a loss how to rectify this error, a girl, one of the attendants on the oven, offered to enter, and mark with a pencil the height at which the thermometer stood within the oven. The girl smiled at M. Tillet's appearing to hesitate at this strange proposition, and, entering the oven, marked with a pencil the thermometer as standing at 260° of Fahrenheit's scale. M. Tillet

began to express his anxiety for the welfare of his female assistant, and to press her return. This female salamander, however, assuring him that she felt no inconvenience from her situation, remained there ten minutes longer, when at length, the thermometer at that time standing at 288° , or 76° above that of boiling water, she came out of the oven, her complexion indeed considerably heightened, but her respiration by no means quick or laborious. The publication of this transaction exciting a great degree of attention, several philosophers repeated similar experiments, among which the most accurate and decisive were those performed by Drs. Fordyce and Blagden. The rooms in which these celebrated experimentalists conducted their researches were heated by flues in the floor. There was neither any chimney in them, nor any vent for the air, excepting through the crevice at the door. Having taken off his coat, waistcoat, and shirt, and being furnished with wooden shoes tied on with lint, Dr. Blagden went into one of the rooms as soon as the thermometer indicated a degree of heat above that of boiling water. The first impression of this heated air upon his body was exceedingly disagreeable; but in a few minutes all his uneasiness was removed by the breaking out of a sweat. At the end of twelve minutes he left the room very much fatigued, but no otherwise disordered. The thermometer had risen to 220° . In other experiments it was found that a heat even of 260° could be borne with tolerable ease. At these high temperatures every piece of metal about the body of the experimenters became intolerably hot; small quantities of water placed in metallic vessels quickly boiled. Though the air of this room, which at one period indicated a heat of 264° , could be breathed with impunity, yet, of course, the finger could not be put into the boiling water, which indicated only a heat of 212° ; nor could it bear the touch of quicksilver heated only to 120° ; nor scarcely that of spirit of wine at 130° . But in a physiological view, the most curious and important point to be noticed is, that while the body was thus exposed to a temperature of 264° , the heat of the body itself never rose above 101° or at most 102° . In one experiment, while the heat of the room was 202° , the heat of the body was only $99\frac{1}{2}^{\circ}$, its natural temperature

in the state of health being 98° . But animals are capable of living in temperatures of extraordinary elevation even in the dense medium of water. Dr. Clarke states, that in one of the tepid springs of Bonarbashy, situated near the Mender, in which the thermometer rose to 62° Fahrenheit, fishes were seen sporting in the reservoir. In the thermal springs of Bahia, in Brazil, small fishes were seen swimming in a rivulet that raises the thermometer to 88° . Sonnerat states, that he found fishes existing in a hot spring at the Manillas at 158° . M. Humboldt and M. Bonpland, in travelling through the province of Quito in South America, perceived fishes thrown up alive, and apparently in good health, from the bottom of a volcano, along with water and heated vapour that raised the thermometer to 210° , being only 2° short of the boiling point. This power of resisting temperature belongs, in an almost equal degree, even to the vegetable world. M. Sonnerat found the *viteæ agnus castus*, and two species of *aspalathus* on the banks of a thermal rivulet in the island of Lucon, the heat of which raised the thermometer to 174° , and so near the water that its roots swept into it. Around the borders of a volcano in the Isle of Tanna, where the thermometer stands at 210° , Mr. Forster found a variety of flowers flourishing in the highest state of perfection. *Convolvæ* and other water-plants are by no means unfrequently traced in the boiling springs of Italy raising the thermometer to 212° , or the boiling point. The temperature at which these beings preserve their life and health, and maintain the heat of their bodies at nearly the same point as is natural to their tribes under ordinary temperatures, is obviously more than sufficient to boil the vegetable, or to roast the animal when dead. Now, this power of resisting temperature the living body owes to the performance of certain vital processes which are excited to extraordinary action under extraordinary circumstances. By the same power it is capable of bearing with impunity intense degrees of cold. In climates and seasons when the thermometer indicates a degree of cold much below zero, the temperature of the animal body continues almost unchanged, and all the functions of life go on without impediment or injury. Some of the lower animals may even be frozen and rendered quite torpid without the loss

of life. The common eel may be reduced to this condition and conveyed thousands of miles in a state of complete torpor, while it may be again restored to the full possession of activity and health, by the cautious application of warmth. And in whatever climate man himself has been able to live, or into which curiosity has led him to penetrate, there, wherever he has been able to trace a vestige of animal being, plants have equally been found flourishing in vigour and adorned with beauty.

Other classes of facts indicate a controlling power equally characteristic of the living body. Seeds endowed with vitality remain unchanged, under circumstances in which they would certainly be destroyed (that is, decomposed and resolved into their ultimate elements) were they destitute of the principle of life. They remain buried many thousand years deep in the bowels of the earth, yet when accident throws them to the surface, and they fall into a soil which is favourable to their vegetation, they immediately begin to develop properties which had lain latent for unknown ages, and spring into active life with all the vigour of a seed formed under our own eye. Hence in the neighbourhood of quarries new plants are continually making their appearance, which had never before been observed to grow near such places. Seeds pass uninjured even through the digestive organs of animals, exposed with impunity to the most powerful of all solvents of vegetable and animal matter, the gastric juice. And what is truly remarkable, irresistible as the action of that wonderful fluid is upon all dead vegetable and animal substance, it has no perceptible influence whatever upon any of those substances as long as they retain their vitality. No living being, when in the stomach of an animal, is acted upon by its gastric juice until the vitality of that being is destroyed. Hence worms are capable of living for an indefinite period in the stomach of animals, and are exposed with impunity to their gastric juice; nor is there any mode of destroying them, but that of introducing into the stomachs of the animal some substance which kills these parasitic creatures, and then they are easily expelled. The walls of the stomach during life are in constant contact with its own gastric juice, without receiving any injury from it; but it

sometimes happens after death, that this fluid corrodes and eats through the very organ that formed it. The egg, like most other living beings, maintains a temperature considerably above that of the surrounding medium: by a delicate thermometer, its vitality, that is, its freshness, may always be ascertained; and as long as it is alive it resists putrefaction under degrees of heat and moisture which cause it to run rapidly into the putrefactive process as soon as it is dead.

The property of hibernation in animals, exceedingly curious in all the circumstances that belong to it, is truly wonderful in its preservative power—a power which maintains the existence of the animal, not only as well as if all its vital actions were in full operation, but, if the observations of some naturalists are to be credited, even under circumstances in which the animal could not live, were its ordinary vital actions in complete play. The state of hibernation itself seems to be produced in order to preserve the animal from the operation of temporary causes, such as states of temperature, climate, and so on, which would be fatal to it. While these states continue, the usual vital processes are either wholly suspended, or go on with an extraordinary degree of slowness: as soon as the former pass away, the latter renew their action, and the animal springs into life with renovated power, safe, during the whole period of its suspended animation, from the influence of physical agents, not only in their ordinary state of energy, but, as has been just stated, in an extraordinary degree of intensity.

The loir, or fat dormouse, which in winter falls into a torpid state, illustrates what may be considered as the lowest degree of hibernation. These creatures possess so little animal heat that it scarcely exceeds the ordinary temperature of the air: their torpor ceases with the cold: a few degrees of heat, about ten or eleven, will reanimate them, and if they are kept during winter in a warm room, they will continue active the whole season; they will then move about, eat, drink, and sleep at the usual intervals, like other animals. When the cold approaches they roll themselves into a ball, and in this state may be found in winter in hollow trees, or clefts of rocks, or in holes in walls exposed to the south; they may be taken

and rolled about without rousing them ; nothing, indeed, seems to awaken them from their lethargy but gradual heat ; if exposed suddenly before a fire they die : resuscitation can only be effected by degrees. In this state, however, although deprived of the capability of movement, with the eyes closed, and in an apparent state of death-like indifference, they possess a feeling of pain when sharply inflicted : a wound or a burn causes them to contract, and to make a slight sort of convulsive leap, which they will repeat several times.

From experiments performed on this species in particular, among other lethargic quadrupeds, by A. M. Mangili of Pavia, it appears that its hybernating or lethargic state takes place only within certain ranges of temperature ; that either too high or too low a degree of temperature prevents it from coming on ; that the torpor is most profound when the temperature is at from 5° to 7° above zero, and that a more intense cold even revives the animal to activity. These experiments shew in the most beautiful manner how completely this singular condition, scarcely to be distinguished from that of death, is under the regulation and control of the vital principle, that principle inducing the state when the cold is at a certain degree, but preventing it from coming on, and even rousing the animal from it when it has actually supervened, if the intensity of the cold increase.

But if the accounts given by naturalists of the hybernating condition of certain birds be deemed worthy of credit, how much more wonderful must appear the preservative power of life, and how much more extraordinary the modifications of state in the same animal of which it will admit ! That the cuckoo hybernates, and that, when accidentally found in its torpid state, it appears like a dead mass of matter ; that it may be rolled about, or even struck with a considerable degree of violence without producing the slightest sign of sensation ; that its respiration and every other manifest vital action seem to be wholly suspended, are well known facts. Equally familiar to us is the annual migration of swallows from our country and their regular return to it in the month of April ; but it is not so generally known that some of these birds, probably the young and the feeble, remain the whole year in Britain, and as the winter approaches,

retiring into the hollows of trees, the clefts of rocks, and the bottom of deep caverns, fall into a torpid state, and continue in a profound lethargy during the cold months. In the severer climates, the fact of their hybernation is still more abundantly attested ; but the most extraordinary statement is that, in such countries, they precipitate themselves into the sea and into deep lakes and rivers, at the bottom of which they remain during winter in a state of profound torpor. If such accounts may be credited, and they are attested by authorities which can scarcely be questioned, how wonderful must be the action of the vital principle in preserving the life of an animal under circumstances so extraordinary, in an element which would certainly be fatal to it in a few minutes in its ordinary state ; with its respiration suspended, its circulation stopped, and its blood—in what condition must we conceive this fluid to remain ? If it coagulate, which it must do in a few seconds, unless under some counteracting and controlling influence, it can no longer be a living fluid, and how then can the animal possibly revive ? But if it do not coagulate, if it remain alive, and therefore fluid, though at perfect rest, and exposed to such a degree of cold for this length of time, how striking an illustration would this most singular fact afford of the uninterrupted and enduring and efficient action of the vital principle, under circumstances which would seem absolutely incompatible with its existence even for a few moments !

Not less remarkably is the influence of this living power exemplified in the protection it affords the body from disease. It often happens, that causes which are injurious to the body, when they do not operate upon it with sufficient intensity utterly to destroy life, are still adequate to disturb its functions, and thus to occasion disease. Against the influence of such noxious agents the living body is endowed with a power of resistance which affords it complete security as long as its vital energies continue vigorous ; but when these decline, the very causes which before made no sensible impression upon it, now prove fatal. Hence the weaker the body the more susceptible it is to the influence of physical agents, and the less it is capable of resisting the influence of those that are noxious. And when at length death does take place, how instantane-

ous and how entire is the change which the body undergoes! During life, in a creature high in the scale of being, how graceful is the rounded form of the limbs, broken only by the undulations which mark the play of the muscles and which indicate their strength! How soft the balmy heat which pervades every part of the frame! How exquisite the variety, the rapidity, the exactness, the strength of the movements! The instant death seizes on this active creature, all its power of motion is at an end; its genial warmth is gone; its muscles become flaccid; the angles of its bones are prominent and sharp; its eyes lose their lustre; its countenance is without expression; its lips are motionless, and its cheeks livid. This livid colour passes rapidly to a blue, a green, a black: the flesh absorbs moisture; one part of it arises in pestilential exhalations, the remaining part becomes a liquid and putrid mass, and the work of destruction stops only when nothing remains of the body but a few earthy and saline particles, everything else being dispersed in air or carried off by water; having entered into new combinations or formed a constituent part of new beings. And the chemical affinities of the agents which produce these astonishing changes, agents which have surrounded the body from the first moment of its existence, why have they not always operated?—for the reason we have endeavoured to illustrate; because, in the former case, the body was alive, and therefore resisted and controlled the influence of these agents; in the latter case, life being extinguished, the body is in the condition of an inorganic substance, and is therefore instantly acted upon by them.

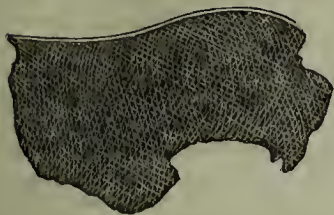
The manner in which physical and chemical changes are effected in inorganic bodies, is either by the change of place in their masses, or by the change of combination in the elementary particles of which they are composed. It is remarkable that life does not counteract the operation of the agents which produce these changes, as might at first be supposed, by retaining in one uniform position the identical particles of which the living body is formed; for no particle of the living body retains its relative position for any considerable time—no particle continues long in the body itself; all are in a state of constant mutation; old particles are every moment

taken away; new particles are every moment supplied: it is by incessant motion among the integrant particles of the living body, not by rest, that its integrity is preserved; and that motion, for the most part, is internal. A circle of actions is established *within* the body, by which certain processes are accomplished which counteract decomposition and retain it in the peculiar condition which, as far as our observations go, is necessary to life. Thus, internal, or, as they are often termed, intestinal actions, counteracting the ordinary influence of physical agents, afford the first distinctive character of life.

2. The second is the power possessed by the living body of assimilating foreign matter to its own substance. The particles of which inorganic bodies consist are held together by mutual attraction: they increase by the juxtaposition of new particles, which are merely superimposed upon the pre-existing mass. The living body is endowed with the power of converting materials of different natures into one homogeneous substance, and of elaborating from that substance the various fluid and solid parts of which it is composed. The plant puts forth its roots into the soil, and abstracting the nutrient particles it finds, converts them into its own proper substance. The animal receives into the interior of its body the different substances from which it derives its nourishment; dissolves them; decomposes them; recombines their elements in new proportions and in different modes, and thus forms all the tissues and all the organs which anatomy displays as composing its structure.

3. A third character by which the living body is distinguished is derived from the peculiar disposition of the materials of which it consists: that disposition is always regular and determinate, constituting arrangement. This arrangement is termed structure; the process by which it is effected is called *organization*; hence the body in which it is found is said to be organized. The most simple, or the ultimate arrangement, in an organized body, as far as it is in our power to trace it, consists of an areolated and spongy substance, forming exceedingly minute cavities, in which the fluids are contained. Of this structure an imperfect conception may be conveyed by the annexed figure.

Fig. 1.



This areolated and spongy substance is disposed in layers: its fibres interlace and intersect each other in every possible direction; thus uniting, it forms tissues; tissues combine, and form organs; organs combine, and constitute the entire body.

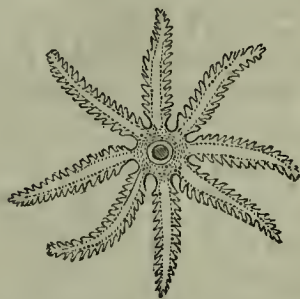
We have thus arrived at three characters which distinguish the living body, namely, the power of resisting, within a certain range, the ordinary operation of physical agents; the power of converting matter of different qualities into its own proper substance, and the power of arranging the substance thus formed in a regular and determinate manner, denominated structure. There are two additional phenomena, which are equally distinctive of it: these relate to its origin and its termination.

4. It is a general law, that living beings derive their origin from pre-existing living beings, by a peculiar process, termed generation. The first origin of a new being is veiled in impenetrable mystery: its first indications of life, however, can, in general, be traced to what is termed a germ; that is, an organized substance, the product of the parent animal. Living bodies form, primitively, part of other living bodies from which they are subsequently detached; from these bodies they derive the degree of development which renders them capable of independent existence: it is the vital motion in the parent stock that communicates to the offspring its vital impulse: it is life that gives origin to life.

As this power of forming a being similar to itself, by which the species is perpetuated, is exceedingly characteristic of the living body, so its power to repair or to reproduce, by internal actions, parts of its own body which may have been lost, is scarcely less remarkable. In the lower animals, entire organs, when removed, are completely and rapidly regenerated. If one or more of the rays of the asterias (*fig. 2*) be destroyed, they are renewed with

surprising rapidity. Blumenbach states that he cut away the entire eye of the water-newt, and that the organ was perfectly restored, only somewhat smaller than the other, in a short space of time.

Fig. 2.



All living beings have this power in a greater or less degree; but, for reasons hereafter to be assigned, the power is greatest in the most imperfectly organized.

5. The last character by which the living body is distinguished, is that of terminating its existence by the process of death. The vital energies by which the circle of actions and reactions necessary to life is sustained, at length decline, and finally become exhausted. Inorganic bodies preserve their existence unalterably and for ever, unless some mechanical force or some chemical agent separate their particles or alter their composition. But, in every living body, its vital motions inevitably cease, sooner or later, from the operation of causes that are internal and inherent. Thus, to terminate its existence by death, is as distinctive of a living being as to derive its origin from a pre-existing germ.

Such is the series of phenomena which we invariably find associated wherever there is life: such a series of phenomena is never found but in a state of life. The assemblage of these particular phenomena is expressed by the general term life. It is natural to conceive that these phenomena are attached to some permanent subject. We are almost irresistibly impelled to the adoption of such an hypothesis, in relation to every subject, physical as well as vital. We say that matter is the permanent subject of certain qualities, such as extension, divisibility, attraction, repulsion, and so on. We say that mind is the permanent subject of certain faculties, such as per-

ception, memory, association, reason. In like manner we imagine that there is a permanent subject, which we name the vital principle, upon which we conceive the phenomena of living beings to depend. But these permanent subjects, these substrata in which qualities are supposed to inhere, must be considered, so far as our real knowledge is concerned, fictions of the imagination. All that we really know are the ascertained phenomena; beyond these everything must, of course, be conjecture; and the most eminent men have fallen, and at this very time are constantly falling, into gross error, by not keeping the distinction here suggested steadily in view.

Organized beings are divided into two great classes, vegetables and animals. The phenomena, we have hitherto stated, are common to both. There are characters by which they are distinguished from each other: these are derived from certain properties which are possessed by the one, but of which the other is destitute. Every living being must possess the power of assimilating foreign materials into its own substance; and, since it is a law of the vital economy that life springs from life only, it must be endowed with the further property of generating an offspring inheriting a nature similar to its own, otherwise every species of creatures would perish with the primitive race. The faculties of nutrition and reproduction must, therefore, be common to all living beings. Vegetables, accordingly, exercise these two functions, but to these their economy is limited. Animals, on the other hand, possess two additional faculties, namely, sensation and voluntary motion; from which superadded endowments they are said to be *animaled*, and are therefore called animals. Thus, vegetables possess only one set of faculties: animals, on the other hand, are endowed with two kinds—first, those which they possess in common with vegetables, and which, accordingly, are called vegetative; or which, because they are essential to the maintenance of life in the individual, and to the perpetuation of it in the species, are sometimes denominated *vital*; these are, nutrition and reproduction: and, secondly, those which are peculiar to animals, but because they belong exclusively to this division of living beings, are termed *animal*; these are, sensation and voluntary motion.

Some ingenious men have inclined to

the opinion that vegetables, no less than animals, possess sensation, and exercise spontaneous motion. There are vegetable phenomena which seem at first view to favour this opinion; but, on strict examination, it will be found that they really afford no support to it. The argument for the sensibility of plants is founded on certain movements which they exhibit, which are truly analogous to those of animals, and which it must be confessed have very much the appearance of spontaneity. The study of the vegetable economy furnishes numerous examples of such motions. The germ, and the radicle of the seed, invariably pursue each its proper direction, although the seed be sown in an inverted position. The plumula always directs itself upwards, while the radicle as certainly strikes downward into the ground. "Several years ago," says Dr. Perceval, who is one of the most ingenious advocates of the perceptivity of plants, "whilst engaged in a course of experiments to ascertain the influence of fixed air on vegetation, the following fact repeatedly occurred to me:—A sprig of mint, suspended by the root, with the head downwards, in the middle glass vessel of Dr. Nooth's machine, continued to thrive vigorously, without any other pabulum than what was supplied by the stream of mephitic gas to which it was exposed. In twenty-four hours the stem formed into a curve, the head became erect, and gradually ascended towards the mouth of the vessel, thus producing, by successive efforts, a new and unusual configuration of its parts. Such exertions in the sprig of mint to rectify its inverted position, and to remove from a foreign to its natural element, seems to evince volition to avoid what was evil, and to recover what had been experienced to be good. If a plant in a garden-pot be placed in a room which has no light except from a hole in the wall, it will shoot towards the hole, pass through it into the open air, and then vegetate upwards in its proper direction. Whether the pond in which it grows be deep or shallow, the water-lily pushes up its flower stems till they reach the open air, in order that the *farina secundans* may perform without injury its proper office. About seven in the morning, the stalk erects itself, and the flowers rise above the surface of the water; in this state they continue until four in the afternoon, when the stalk becomes re-

laxed, and the flowers sink and close. The sensitive plant contracts on the slightest touch, and immediately folds up its leaves. The flowers of a great variety of plants alter their direction according to the circumstances in which they are placed. A hop-plant, turning round a pole, follows the course of the sun, from east to west, and even dies if forced into an opposite line of motion. The regular movements by which the sun-flower presents its splendid disk to the sun, have been the subject of universal admiration, both in ancient and modern times:—

The lofty follower of the sun,
Sad when he sets, shuts up her yellow leaves,
Drooping all night; and when he warm returns,
Points her enamour'd bosom to his ray.

The lateral leaflets of the *hedysarum gyranis* present a constant alternation of elevation and depression, and this regular and successive movement is conceived to be connected with the function of respiration. The stamina of the *berberis vulgaris*, and of several other plants, move towards the stigma, in a manner which has struck every observer with its similarity to spontaneous motion. The roots of plants which proceed in pursuit of proper nourishment, and which alter their course the moment they approach a situation which would be injurious to them, afford examples which still more strikingly resemble spontaneous movements. If a wet sponge be placed near a root exposed to the air, the root will direct its course to the sponge: if the place of the sponge be changed, the root will vary its direction. The claspers of briony shoot into a spiral, and lay hold for support of whatever may come in their way. If, after completing a spiral of three or four rounds, they meet with nothing to sustain them, they set out afresh in search of support, by altering their course.

But, curious and interesting as many of these movements are, they are inadequate to prove that vegetables possess either sensation, that is, sensation attended with consciousness, or voluntary motion. They are referable to a power possessed in common by plants and animals, namely, the power of contracting on the application of a stimulus. Contractility is truly a vital power: it is possessed only by an organic being; it is possessed in common by both classes of organic beings; but it is constantly exercised, even in the animal, without consciousness, and therefore of

necessity without volition: whence the exercise of it in the vegetable cannot possibly prove that it is attended in this lower order of beings with the possession of consciousness. But that the vegetative functions are performed without consciousness, we have a still more striking proof in ourselves: for man exercises both classes of functions, the vegetative and the animal. By observing what passes within ourselves, we see that there is no connexion between mere vegetative life and sensation: the latter is a totally distinct and higher faculty, superadded to the former. We are conscious that we live; we are not conscious of the operation of the vegetative faculties by which we live. Of all the processes by which the aliment is converted into blood, and the blood into the proper substance of the body, complicated as the processes, and numerous and incessant as the motions are by which they are performed, we are wholly insensible. There can, therefore, be no reason to suppose that these functions are attended with consciousness in the vegetable, in which all the processes are so much more simple. No motions of the vegetable indicate spontaneity more strikingly than the motions by which a wound, attended with the loss of substance, is healed in the animal body. In this process new fibres are formed, which arrange themselves, not only as if they were animated and intelligent, but the degree of wisdom with which they are disposed is perfect: yet all this is effected, not only without our having the least knowledge of the mode in which it is done, but even without our being sensible that it is done at all.

The distinctions we have endeavoured to establish between animal and vegetable bodies remain therefore unsubverted; but, besides these, which may be considered as primary, there are other characters by which they are distinguished, which, though not so essential, are still very striking.

Vegetables in general are separable by a horizontal line into two parts, one of which ascends and is contained in the air; the other descends and is contained in the earth. Animals in general are separable by a vertical line into two equal halves, whence their body is said to be symmetrical, that is, divisible by a median and vertical line into two equal and similar lateral portions. Vegetables consist of an areolated tissue which is often firm, hard, and unyielding; of

ascending and descending vessels; of spiral tubes; and of peculiar fusiform bodies termed closters. Animals consist of an areolated tissue, which is always soft and elastic, and which for the most part, at least in all the higher animals, is moulded into vessels which perform a proper circulation. The organs of vegetables, few and simple, are placed on the exterior of the body: the organs of animals, extremely numerous, often wonderfully complicated, are almost always placed in the interior of the body. Vegetables consist of three ultimate principles only, namely, carbon, oxygen, and hydrogen: animals consist of four ultimate principles, namely, carbon, oxygen, hydrogen, and azote. Some few vegetables, it is true, contain a minute quantity of azote, but even in these this substance is confined to particular parts of the plant, and does not enter as a constituent element into its composition.

The simplicity of the structure of the vegetable exhibits a striking contrast to the complexity of the animal organization; yet nothing is given to the animal which its mode of life does not absolutely require. For the simple functions performed by the vegetable, a simple structure is sufficient; for the complicated functions exercised by the animal, complicated organs are indispensable. Nature is never prodigal and seldom profuse. The addition of the peculiar faculties of the animal rendered a modification of the common or vegetative faculties absolutely necessary—a modification which could not be effected without increasing the complexity of the mechanism. The vegetable, fixed to the soil which contains its nourishment by its roots which absorb that nourishment, requires no special organ for holding and accumulating its alimentary matter. The animal, not being fixed to the soil, endowed with the power of locomotion, constantly changing and delighting to change its place, must transport with itself the nourishment necessary for its support. Hence the necessity of a special organ for containing its aliment: hence the necessity of modifying its mode of nutrition. That modification is made, in general, by furnishing the animal with an internal cavity, within which it deposits the substances proper for its nourishment. In the coats which form the walls of this cavity are placed the orifices of vessels which absorb the nutrient particles. This cavity, with its contents, is to the animal what the soil

is to the vegetable, and its absorbing vessels constitute the internal roots of the animal.

A second modification, equally indispensable, arises out of the necessity of conveying the nutritive matter to different parts of the body. A considerable force is required to propel the nutritive fluid over its extended surface. For the supply of this force new expedients must be adopted: there must be a circulation of the nutritive fluid: for this purpose vessels must be furnished to contain the fluid, and an engine must be constructed capable of generating a force adequate to communicate to it the requisite impulse. It is easy to see that a communication must next be established between the digestive organ and the vessels which carry on the circulation. And thus, if we were to trace the animal organization to its highest state of complexity, we should perceive that that complexity was absolutely requisite for the due exercise of the higher faculties with which these higher beings are endowed.

The matter of which organic bodies consist is precisely the same as that which is found in the inorganic: it is not a difference in the nature of their component particles, but a difference in their arrangement, that constitutes the essential distinction between those two great classes: the very name of organic bodies points to this fact; for they are denominated organic, because the matter of which they consist is invariably arranged in a peculiar manner termed organization. Dead, or inorganic matter, arranged in this peculiar manner, and modified according to certain unknown laws, becomes organic: what the modification is by which inorganic is converted into organic matter we are wholly ignorant.

It has been stated that the ultimate elements of vegetable bodies are reducible to three, namely, oxygen, hydrogen, and carbon, the former existing in a gaseous, and the latter in a solid state. The ultimate elements of animal bodies are four, namely, oxygen, hydrogen, carbon, and azote. In the animal body are also found the following elementary or simple substances, phosphorus, calcium: these are found in very considerable quantity: sulphur, iron, manganese, silicium, iodine, chlorine: these exist in minute quantities: and to this list it may, perhaps, be proper to add caloric, light, the electric and the magnetic fluids.

Having premised these fundamental observations relative to the nature, the properties, and the distinctions of inorganic bodies, and of vegetable and animal beings, we proceed to give a more particular account of the structure and functions of the animal body.

If we examine an animal high in the scale of organization, we are struck with the variety of its component parts and with the complexity of their structure. By analytical investigation, it is ascertained that these parts, various and complex as they appear, consist only of the elementary bodies which have been just enumerated, and which are called elementary, because they are not capable of reduction, by any known process, into substances that are more simple. These inorganic substances combine together in different numbers and different proportions, under the unknown circumstances which constitute the condition of life, and thus form all existing varieties of organic matter.

By synthetical investigation, it is ascertained that some of these elements combine together in definite proportions, namely, three and three, four and four, and so on: the result of such combinations is the formation of what are termed the Proximate Principles of animals. A proximate principle is the primary combination of two or more of the elementary substances in definite proportions. Of these the chief are albumen, fibrin, gelatin, mucus, casein, olein, urea, uric acid, osmazome, &c.

The component substances of the animal body are invariably disposed in two forms—fluids and solids. The fluids are contained in the solids: both are mutually dependent; both possess an analogous composition; both are in continual motion and pass without ceasing from the one into the other. Every animal consists of a union of both; that union is indispensable to animal life.

O, the Animal Fluids.

The absolute quantity of the fluids contained in the animal body it is difficult to ascertain, because it varies according to varying circumstances, and in the same animal is different at different periods of life, and according to the state of health and of disease. Invariably the younger the animal the greater the quantity of the fluids. The embryo of all animals when it first becomes appreciable by the senses, appears to be

almost entirely fluid. As it grows and is developed, solid parts are gradually added. The quantity of the fluids successively diminishes until the animal arrives at mature age.

Many experiments have been made to ascertain the relative proportion of the fluids to the solids in the human body. Chassier placed a dead body, weighing 120 lbs., in a heated oven: after desiccation for several days he found the weight reduced to 12 lbs. In mummies, in which the abstraction of the fluids is complete, there is always found a remarkable diminution of weight, some of them not weighing more than 7 lbs. The proportion of the fluids to the solids at the adult age in man is estimated, according to the lowest computation, as 6 to 1, and according to the highest, at 10 to 1.

The fluids differ greatly in their density. Some exist in the state of gas: others in the state of vapour: some are extremely thin and transparent, as that of the serous membranes, or the membranes which line the great cavities of the body, as the thorax and abdomen: others possess considerable consistence, as some of those secreted by the mucous membrane—the membrane, for example, that lines the air-passages. Some exist in exceedingly minute quantity, as the delicate fluid contained in the internal organ of hearing: others form a large part of the bulk of the body, as the blood. Some are intimately combined with the animal solid; others are contained in minute, delicate, solid areolæ: some are poured out on the surface of solids, particularly of membranes; others are contained in membranous bags or reservoirs, and a great number are contained in distinct vessels.

They are composed for the most part of water, in which the various component substances of the body are held in solution. It is a very curious fact, that many of them consist of masses of globules. These globules can in general be seen only by the microscope. They were discovered almost as soon as the microscope was invented, but the observation was very generally neglected until recently. For reasons which can scarcely be explained at present, the fact is found to possess great interest and importance; and, at this very time, some of the most intelligent and skilful physiologists are engaged in investigating the subject, so that it is probable that many things, which must now be considered as doubt-

ful, will soon be determined. These globules are found principally in the nutritive fluids, namely, the chyme, the chyle, the lymph, the blood, and, in some of the secreted fluids, as milk, pus, and so on.

The properties of the fluids are either physical, chemical, or vital. There would be no utility in exhibiting a collective view of these physical properties: it will be better to consider each separately, when the more important fluids are treated of in detail. Their chemical properties are very important. All the great actions of life are intimately connected with them. Their influence over all the processes which are constantly going on in the economy is so great, that if the body may be called a machine, as, from the admirable adjustment of its various parts, it may be termed with striking appropriateness, it may at least with equal truth be denominated a laboratory, in which the most important and extensive chemical actions are taking place every instant. In general the chemical composition of the fluids is the same as that of the solids: both contain the same proximate principles—albumen, gelatin, fibrin, and so on; and in the living body there is a continual transformation of fluids into solids, and of solids into fluids. Whatever may be the case with the other fluids, the blood at least exhibits phenomena which are perfectly analogous to those of the living solid. If blood be taken from an artery or vein, and kept at rest at the same temperature which it possesses in the living body, after a certain time it undergoes the process of coagulation; that is, it separates into several distinct portions, some of which are fluid and some solid: it is now no longer a fluid substance; it dries; and this change into a substance partly fluid and partly solid, takes place, it is conceived, subsequently to its death, and in consequence of its death, because, as long as it continues to be a living fluid in a living vessel, it preserves its fluidity. Nor does it owe the maintenance of its fluidity to its circulation; to mere motion at a given temperature: for experiments have been performed, in which the circulation of the blood has been imitated in artificial tubes, kept at the natural temperature of the blood; but, even under these circumstances, this fluid has always coagulated, just as if it were in a state of perfect rest: the inference is, that the blood maintains its fluidity in the living

body, in consequence of its being endowed with the property of life. The blood may be shot dead instantaneously, as it is by a stroke of lightning. It is also subject to manifest disease, as is strikingly exemplified in certain cases of poison, in certain kinds of fever, and in the remarkable disease termed scurvy; but nothing in the slightest degree analogous to the phenomena of disease can be exhibited by any body which is not endowed with life.

The fluids have been differently arranged, from time to time, according to the different doctrines which have successively prevailed in the schools. The ancients conceived that there were four elements, out of which every substance, inorganic and organic, was formed. In conformity with this notion, they divided the fluids of the animal body into four principal humors: namely, the blood, the lymph or puita, the yellow bile, and the black bile. While it is difficult to form a perfect arrangement, physiologists have suggested different principles as the basis of division. i. Some have proposed to found it on the use which the fluids serve in the economy. According to this principle, the fluids have been divided into primary and secondary. The primary are the alimentary, or the recrementitious; these include the fluids, which conduce to the nutriment of the body. The secondary, or the excrementitious, comprehend those which are secreted, in order to be carried out of the body; that is, in order to remove from the system principles which are either useless or noxious. ii. Others have proposed to class the fluids according to their *mode* of formation. Hence they divide them into—1. Chyme, Chyle; 2. Lymph; 3. Blood; 4. Fluids of perspiration, and exhalation; 5. Follicular fluids; 6. Glandular secretions.—iii. A third suggestion is to divide them into four great classes: namely, 1. Those which form the blood; 2. The blood itself; 3. Those which are formed from the blood; 4. Those which are returned to the blood from all the parts of the body. This arrangement is simple and comprehensive, but perhaps the most convenient is that which is founded on the chemical composition of the fluids. iv. According to this principle, the fluids are arranged into the eight following classes:—1. The aqueous; 2. The albuminous; 3. The mucous; 4. The gelatinous; 5. The fibrinous; 6. The oleaginous; 7. The resinous; 8. The saline.

The advantages of this classification are, first, that for every fluid an appropriate place is readily found; and, secondly, that as all the fluids are secretions, this arrangement will prove useful in treating of the function of secretion, and in enabling us to exhibit a comprehensive view of the products formed by that process.

Of the Animal Solids.

The solid parts of the animal body are derived from the fluids. They are formed out of them by a peculiar process, hereafter to be described, termed secretion. After the solids are once formed, they depend for their integrity upon a continual supply of the fluids.

In the human body, the proportion of the solids to the fluids has been already stated to be about one part in nine or ten. The solids are composed of the same physical substances as the fluids; are reducible by analysis to the same chemical elements, and form, by the primary combination of these elements, the same proximate principles.

Every animal solid is either concrete or fibrous: that is, it is either without arrangement, like jelly or glue, or it is disposed in the form of minute threads, which are termed fibres. When arranged in different structures, these fibres either retain the form of threads, or are disposed in minute plates or laminæ: hence, whatever animal structure be examined, it is found to be either fibrous or laminous.

In combining to form the different animal structures, the solid parts are disposed in a great variety of modes. Of these, the chief are into filaments, fibres, tissues, organs, apparatus, and systems.

The filament is the elementary solid. A fibre consists of a number of filaments united together. A tissue is composed of fibres, arranged in a particular order. An organ is a compound body, consisting of a specific arrangement of different tissues. The most simple organ is always a very compound body. If we examine a muscle, for example, we find that it consists first of the muscular fibre; then of a distinct envelop, formed of a particular tissue, the cellular, and next of a peculiar substance termed tendon. In like manner a nerve consists of a substance of a peculiar nature, constituting the nervous matter, which is always inclosed in a distinct membrane, termed the neurilema. The most

simple gland consists of a congeries of many different vessels, united by cellular tissue. The eye, the ear, the viscera, are exceedingly complicated organs, consisting of many different tissues, arranged in many different modes. Every organ performs a specific action, or exercises, as it is termed, a particular function. Life is always observed in connexion with the exercise of these functions: hence the organs are termed the instruments of life.

An apparatus is an assemblage of different organs, all of which concur to the production of some definite object. The apparatus of digestion, for example, consists of the organs of mastication, of the organs of deglutition, of the stomach, of the duodenum, of the pancreas, of the liver, of the lacteal and absorbent vessels, and of the glands connected with these vessels, to which ought in strictness to be added the lungs. Numerous and different as these organs are, varied and even opposite as is their action, yet they all concur to one end, namely, the formation of blood. The organs which compose an apparatus, individually considered, may be exceedingly different in their structure and function. They may have nothing similar in organization; the products of their action may be of opposite natures; but they are associated together in one class, on account of their conjoint operation in the production of some common end.

A system, on the contrary, is an assemblage of organs, all of which possess the same, or an analogous structure. Thus all the bones of the body, however different in figure, in magnitude, in disposition, have one common structure: hence they are all associated in one great class, which is termed the osseous system. In like manner, whatever be the form, disposition, or action, of the different muscles, they all possess one common structure, and therefore are arranged into one class, termed the muscular system. For the same reason, all the vessels of the body are classed together under the name of the vascular system; all the ligaments under the name of the ligamentous system, all the nerves under that of the nervous system, and so on.

Some of these tissues are so extensive, are found in so many parts of the body, and enter in so large a proportion into the composition of all the different organs, that they are distinguished by the appellation of common. Thus phy-

siologists speak of the common cellular tissue, of the common integuments, or the common dermoid tissue, or skin, and so on.

Taking this view of the animal body, which is a truly physiological view, we may say, that, excepting in the very lowest animals which appear to consist of a homogeneous substance similar to jelly, it may be considered as an aggregate formed of a number of organs; that each organ is itself composed of a variety of tissues, and that each tissue is more or less common to all the organs.

Varied and almost innumerable as the different solids at first view appear in the higher animals, as in man, yet, when attentively examined, it is found that they may be all included in the following substances, namely, bones, with their cartilages and ligaments, which may be considered as appendages to the bones; muscles with their tendons; membranes of various descriptions; sacs of different structures; vessels of different kinds, and nervous matter. There is no solid of the body which may not be comprehended under one or other of these substances. And these substances again, widely different as they appear both in composition and structure, may all be reduced by careful and accurate analysis to three, namely, the Cellular, the Muscular, and the Nervous Tissues.

1. *Of the Cellular Tissue.*

Of all the animal solids the cellular tissue is the most simple in structure, the most abundant in quantity, and the most extensively diffused. It enters as a constituent element into every other solid. It composes the main bulk of bones; the strength, and hardness of these firm and solid bodies depending on an earthy matter deposited in cells formed of cellular tissue. It affords an external sheath to every muscle; it is interposed between every fibre, of which every muscle consists; it incloses in a distinct envelop every nervous fibre; it composes almost the entire bulk of tendon, ligament, and cartilage; it enters largely into the composition of hair, nails, and other similar parts connected with the surface of the body. The enamel of the teeth is said to be the only solid in which it cannot be detected. It unites together all the different parts of the body; it fills up all the intervals between them. Were it possible to remove from the bones their earthy particles, and from the soft parts the muscular fibres, the nervous

matter, and the fat; were it possible at the same time to empty the vessels and to evaporate the fluids, the body would remain nearly of the same size, and be sustained nearly of the same form by means of this substance alone. It may, therefore, be considered as the basis to which all the other parts of the body are attached; as the mould into which all the other kinds of matter are deposited.

When examined with the naked eye, and gently distended, this substance is found to be composed of fibres or threads of extreme delicacy, finer than the finest cobweb. These fibres intersect each other in all directions, so as to leave between them minute spaces which are termed areolæ, or cells. (*Fig. 1.*)

It is from this cellular appearance that the tissue derives its name. But this cellular arrangement disappears immediately when the distension is discontinued. Without mechanical distension there is no appearance of cells either in the living or the dead body. The fibre itself is solid. It was to demonstrate this, in opposition to the opinion of Boerhaave, who conceived that the ultimate fibre is a vessel, that Haller engaged in those laborious investigations which have made anatomists and physiologists so intimately acquainted with the structure and distribution of this substance. The result of the researches of this celebrated physiologist was the establishment of the fact, that the basis of the animal frame is a solid fibre to which the vessels are added as distinct appendages.

Of the cellular tissue are composed—
1. membrane; 2. bones; 3. the sheaths which inclose the more tender and delicate structures; 4. the substance by which the different parts of the body are united together; 5. the substance by which the interstices between the different parts are filled up. Of all these substances, by far the most extensive and important is membrane. The great bulk of the animal solids consists of membrane, that is, of cellular tissue arranged in the form of membrane. 1. Membrane forms the general covering of the body, lining every part, both of its external and internal surfaces. 2. It affords a particular covering for its individual structures. 3. It lines all the cavities in which the principal organs are situated. 4. It composes the principal part of all vessels. 5. It forms what is termed the parenchyma, or the solid part of all the viscera. 6. It constitutes the main bulk.

of all glands, whether those which are appropriated to the office of secretion, or those which are attached to the absorbent system.

Membranes are divided into different kinds, each of which performs distinct and appropriate offices in the economy. 1. Serous membranes; those which comprise all the sacs or shut cavities of the body, such as those of the chest and abdomen. 2. Mucous membranes; those which line all the air-passages; compose all the air-cells of the lungs; invest the whole track of the alimentary canal from the mouth to the anus, and thus form a principal part of the extensive and important organs of respiration, digestion, and excretion. 3. Fibrous membranes; those which compose tendon, aponeurosis, ligament, and so on. However widely many of these substances differ from each other in their general aspect and even in their intimate structure, yet that they are all modifications of cellular tissue, the evidence is so complete, that few anatomists or physiologists of the present day dispute it; and recent investigations have elicited new facts which directly prove the correctness of the opinion.

2. Of the Muscular Tissue.

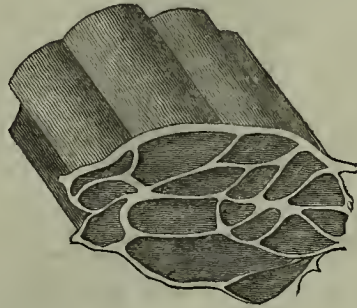
The second tissue, which, on an analysis of the animal solid, is found to enter into the composition of the body, is the muscular. This tissue consists of a substance of a peculiar nature, which is arranged in the form of fibres of extreme delicacy. When examined by the naked eye, and taken in its most recent state from the dead body, these fibres appear soft, reddish coloured, solid, of various diameter, placed parallel and close to each other (*fig. 3*).

Fig. 3.



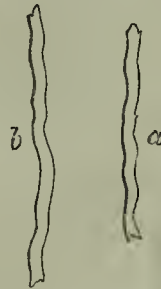
The muscular tissue is arranged in two different modes; first, in the masses properly termed muscles, and, secondly, in a thin membrane-like expansion, denominated muscular coats. Proper muscles are composed of filaments (*fig. 5*): the aggregation of a number of filaments forms what is termed a fibre (*fig. 3*): fibres are collected into small bundles which are called fasciculi (*fig. 4*).

Fig. 4.



Prochaska, who has employed incredible labour in investigating the mechanical arrangement of the muscular fibres, and whose account is the most exact, maintains in the most positive manner, that the ultimate filament is discernible, and that it is always and everywhere of the same magnitude. He computes its size to be about 1-50th part of the diameter of the red globule of the blood. *Fig. 5* represents two ultimate fila-

Fig. 5.



ments; *fig. 3* represents a number of filaments united together to form a fibre; *fig. 4* represents numerous fibres united together, the whole forming a fasciculus.

Other anatomists maintain that it is only the imperfection of our senses and instruments which leads us to imagine we can perceive an ultimate filament. They suppose that the division of the filament does not stop where it seems to us to terminate, and that if our vision were improved, we should see that it still

goes on dividing and subdividing indefinitely.

The ultimate filament, as far as has yet been observed, is destitute of any cellular covering; but every fibre is inclosed in a distinct cellular sheath (*fig. 6*):

Fig. 6.

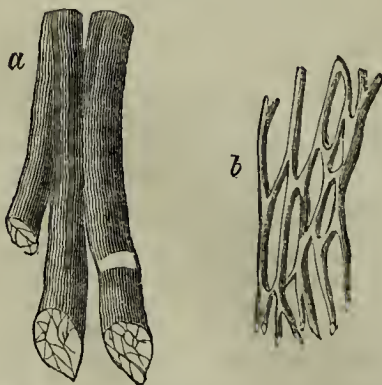


a, representing the fibres covered by the sheath;
b, the fibres with the sheath removed.

every fasciculus is also inclosed in its own envelop (*fig. 4*); and lastly, the muscle itself is invested with a separate cellular coat which covers it completely at every point, excepting where its ends are attached to the bones.

The muscular fibres which are disposed in the form of a membranous expansion, and which constitute the muscular coats, appear to the eye to be very different from proper muscles, but they only, or at least chiefly, differ in the mechanical arrangement of their fibres: the nature of both is precisely the same. Their fibres, instead of being collected into fasciculi, are disposed in layers, and instead of being parallel they interlace (*fig. 7, a*); and according to Prochaska even anastomose, that is, join each other by a union of substance (*fig. 7, b*).

Fig. 7.



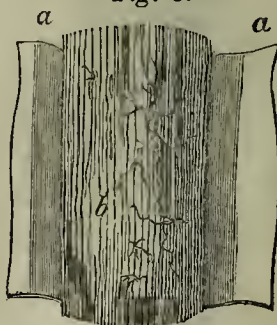
3. *Of the Nervous Tissue.*

The third tissue, into which the animal solid is resolvable, is the nervous. The nervous tissue consists of two substances, which, as far as the eye can distinguish, appear to be entirely distinct from each other. The one is sometimes named, from its colour, cineritious or grey; from its position, cortical; and, from its consistence, pulpy or gelatinous. This last is its most important character. It appears to be composed, for the most part, of a congeries of blood vessels. The other substance is termed white or medullary. It is of firmer consistence than the pulpy. The peculiar matter of which it is composed is arranged in the form of minute and delicate fibres. In every part of the nervous system which constitutes a distinct nervous apparatus, both substances are conjoined. Neither the pulpy nor the fibrous alone forms a distinct organ: the union of both is necessary to constitute an instrument capable of performing a specific function.

When the nervous system first begins to be apparent in the lower animals, it consists only of minute and exceedingly delicate threads. In all the more perfectly organized animals, the nervous substance is disposed in four different modes, forming four distinct parts or organs, namely, nerves, ganglia or appendages to particular nerves, the spinal cord, and the brain. Of the three latter organs, which are merely particular arrangements of the common mass of nervous matter, we shall speak more particularly when we treat of the functions of the nervous system, the plan to be observed in this paper being to precede the account of every function with a description of its apparatus.

A nerve is a cord of a white colour (*fig. 8, b*). It is composed of fibres of

Fig. 8.



a a, which represents the sheath of the nerve reflected.

nervous matter (*fig. 9*). These fibres, as soon as they become visible to the

Fig. 9.



goes on progressively to divide and subdivide, until its branches become so minute as to be invisible; or, on the other hand, that they arise by numerous and invisible branches, which unite to form larger and larger vessels, until they ultimately constitute only a few trunks. The muscular and nervous filaments never divide and subdivide in this manner. It is the opinion of the most eminent anatomists, that there is a diameter beyond which they no longer diminish. That diameter they maintain is quite uniform in each. According to Fontana, the ultimate nervous filament is about twelve times larger than the ultimate muscular filament. This accurate observer represents the primitive nervous filaments as placed close and parallel to each other, similar to those of the muscles (*fig. 8 b*): and with his account, in general, the descriptions of Prochaska, Monroe, and the more recent dissections of Reil, agree in every important particular. Reil is quite positive in stating that the ultimate nervous filament is visible. Probably the more correct statement is, that there is a filament of a certain diameter, beyond which no means hitherto employed have succeeded in tracing its subdivisions. Reil agrees with Fontana in representing the ultimate nervous filament as much larger than the muscular.

Of the Elementary Structure of the Animal Solids.

naked eye, are perceived to differ in size from that of a hair to the finest fibre of silk. These fibres unite into bundles, which, as in muscle, are called fasciculi. The fasciculi uniting, form the cord to which the name of nerve is given. As in the muscle, the ultimate filament appears to be destitute of any cellular covering: but every fibre is inclosed in a distinct sheath, of exceedingly delicate cellular tissue. In like manner, every fasciculus is enveloped in a similar sheath; and, lastly, the cord itself is inclosed in its own cellular envelop (*fig. 8 a. a*). The cellular covering of the nerve is termed its neurilema.

It will be shown hereafter, that in the vascular system, either all the vessels proceed from one large trunk, which

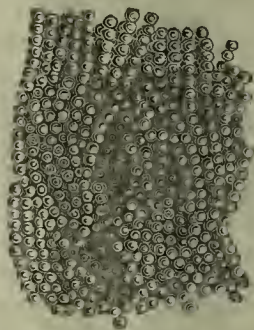
Hitherto we have described the structure of the primitive tissues only as far as they are visible to the naked eye. Thus far the agreement in all the essential points, in the descriptions of the most able observers in all ages and countries, is truly remarkable. The study of the elementary structure of these tissues opens a vast field of inquiry of great interest and importance, in which the labourers have hitherto been comparatively few; and their researches, made at distant intervals, and neither repeated so often nor carried so far as is requisite to ascertain the truth, have been attended with less satisfactory results. Investigations of this nature are attended indeed with peculiar difficulty. They require unwearied perseverance, extreme accuracy, great patience, and a dexterity with the hand united with a delicate discrimination of the eye, that belong to few, and the requisite use of which rare endowments

can be acquired only by long practice. Nor could such investigations be successfully pursued at all, did we not possess the means of magnifying the bulk of the object examined many hundred times beyond its real volume. Without doubt the microscope is an instrument in the use of which much caution is required; but that, when care is taken to guard against its sources of fallacy, it is capable of communicating real and valuable information, it were idle to dispute. It is remarkable, that one of the very first results of the employment of the microscope on its discovery was the detection of the globular structure of the primitive tissues of the animal body. Lewenhoeck, who, about the middle of the seventeenth century, applied the microscope to the examination of the different tissues of the human body, states expressly, that the ultimate filaments of which they are composed, are formed of globules of extreme minuteness. "Having exposed them (the ultimate muscular filaments) to my microscope," he says, "I saw to my wonder that they were made up of very small conjoined globules, which, in smallness, seemed to surpass all the rest; this I took notice of frequently." He adds, "I have used several methods to see the particles of these carneous filaments, and have always found that they are composed of such parts to which I can give no other name than a globule." This statement was regarded with great distrust: it was, however, confirmed by many able observers; but from that period to the present, at different intervals, it has been the subject of controversy, and the controversy continues to the present day. We have already stated, that the subject is at this very time engaging the attention of the most distinguished physiologists of Europe, and their researches will probably, at no distant period, ascertain the truth beyond reasonable doubt. In the mean time, we may give, in a few words, the results to which the most careful microscopical observers think they have arrived.

If the cellular tissue, when in a state perfectly natural, having been subjected to no preparation capable of altering its properties, be examined with a microscope of high magnifying powers, it appears to consist entirely of minute particles, of a globular form (*fig. 10*). These globules are arranged in irregular series, forming lines of different lengths, which take every possible direction, and

intersect each other in every possible manner. All these circumstances are represented in *fig. 10*. It is remarkable, that from whatever part of the body the tissue be taken, the arrangement of the elementary globules, and their diameter, appear to be uniformly the same. That diameter is estimated at about the $\frac{1}{8000}$ th part of an inch.

Fig. 10.



It is a very curious and interesting fact, that an examination of this tissue in the inferior animals, especially in the four classes of the vertebralia, has led to the discovery, that in all the tribes of the mammalia, in birds, in reptiles, in fishes, it is composed of globules, which have precisely the same general appearance, and which are exactly of the same magnitude. Subsequently, the examination has been extended to invertebrated animals, in all of which this tissue presents the same globular structure, with this difference only, that while the greater number of the globules are of the same bulk as in the vertebrated animals, they are mixed with others of a larger volume, it is supposed because these larger globules consist of a union of several of the elementary.

The elementary structure of the muscular tissue has been examined with the like care, and with the same apparent result. In this tissue also, the ultimate filaments appear to consist of globules: these globules are arranged in similar linear series; but the direction of the series is always different (*fig. 11*); in the muscular tissue the direction is invariably parallel. The fibres never intersect each other, like those of the cellular tissue, and this is the only discernible difference, for they are of the same figure and magnitude as the cellular. The same curious fact has been observed with regard to the uniformity of the structure of this tissue in all the inferior animals, and the identity

of the structure with that of the same tissue in man. The figure and diameter of the globules, and the parallel direction of the linear series, are the same in whatever creature they are examined.

Fig. 11.



Whatever doubt may be entertained, and whatever controversy may be agitated respecting the accuracy of these observations, in relation to the cellular and the muscular tissues, few examiners have called in question the globular structure of the nervous tissue. This structure is, probably, more visible in this than in the other tissues, because on account of its more soft and delicate texture it is more transparent. All the physical characters of the globules of the nervous are identical with those of the cellular and muscular tissues (*fig. 12*).

Fig. 12.



Whether they are examined in the brain, in the spinal cord, in the ganglia, or in the nerves, they have the same figure and the same diameter, and no difference of any kind can be distinguished in them, from whatever animal the specimen under examination be taken.

The general conclusion deducible from these series of observations is, that every animal solid consists of molecules, all of which possess a determinate figure and a uniform magnitude; and that these constitute the elementary particles,

by the various combination of which all the tissues of all animals are composed. Supposing the correctness of these observations to be established, we might say, that a globule of about the diameter of the $\frac{8}{1000}$ th part of an inch is the elementary organic molecule, of which every solid of every animal body is composed, because the analysis of every such solid might be carried on until we come to such a globule, but no further, at least by any instrument we at present possess. This globule might, therefore, be considered as the elementary organized corpuscle. Thus it would appear, that from the zoophyte up to man there is in the structure of all the different tissues not only a most striking similarity, but an absolute identity. We know, from the study of her laws, the simplicity of the means by which nature works; but these discoveries show the simplicity of the material with which she constructs the most varied of her productions, and renders that variety, infinite as it is, still more wonderful and admirable.

The result of the preceding researches suggests the further inquiry, whether the globular form which has been described be peculiar to matter assimilated to living beings, and consequently depend on the influence of life; or whether it be referable to the influence of laws purely physical, in consequence of which certain substances assume this form whenever they pass from the solid to the fluid state, in the same manner as salts in crystallizing are arranged in determinate figures. The experiments which have hitherto been made relative to this subject favour the opinion that it is the result of physical laws. Of these, one of the most remarkable is that performed by Prevost and Dumas. By the action of electricity, fluid albumen is converted into a white coagulum. On examining with the microscope the coagulum thus formed, these physiologists found that it abounds with globules precisely similar to those of the blood when deprived of its external envelop, and to those contained in serum, milk, and pus. They observed also, that these globules showed the same disposition to form series, or aggregates, as in the primitive tissues. Dr. Edwards has further established, by experiment, that the same phenomenon takes place whenever the coagulation of albumen is effected by the action of heat or of chemical agents; that when the serum of the blood, which

always contains in its fluid state a considerable number of globules, is coagulated either by evaporation or by the addition of an acid, or of alcohol, a prodigious quantity is formed; that the same result is obtained by the solidification of the vitreous humor of the eye, of the mucus secreted by the snail, and of that which surrounds the eggs of the frog; that the same is the case with gelatine; that if a small quantity of acetic acid be added to the filaments which compose the substance of the sturgeon, which is regarded as almost pure jelly, its globulous structure becomes perfectly manifest, and that if this substance be dissolved, and then reconverted into a solid, these globules again reappear, and that precisely the same phenomenon is produced by the conversion of a solution of fibrine from a fluid to a solid state. Thus it appears that albumen, gelatin, fibrin, &c. or the proximate animal principles, assume a globular form whenever they pass from the fluid to the solid state, whatever be the cause which produces that change. If the uniformity and universality of this curious fact be hereafter established, it will probably open the path to new and interesting discoveries relative to some of the most important functions of the animal economy. In the mean time it may be observed, that the view which has been exhibited of the elementary structure of the animal tissues, discloses a series of facts, which are in perfect harmony with the ordinary operations of nature. From the most simple vegetable up to the polypus, from the most simple polypus through all the ascending scale of being up to man, the characters of life are nearly the same: that the ultimate structure of the substances to which life is attached should therefore be similar, would be in perfect harmony with the great plan on which we know that all the operations of nature, with which we are acquainted, are conducted. But no consideration should induce us to acquiesce in anything as a fact, until it is fully ascertained; and it should be borne in mind that the entire series of observations relative to the globular structure of organized bodies is at present a subject of controversy, some of the most eminent authorities maintaining that they are correct, and others contending that they are fallacious.*

Of the Properties of the Primitive Tissues.

1. Each of the primitive tissues that has been described possesses peculiar and specific properties. Those which belong to the cellular tissue are wholly physical: they consist of four, namely, cohesion, flexibility, extensibility, and elasticity. Cohesion must necessarily belong to every solid substance; and it is required, in the animal tissues, because, in the performance of many of the vital functions, a considerable degree of force is exerted. The different parts of the body are continually changing their bulk, and varying their relative position: the tissues of which they are composed must therefore possess a considerable degree of flexibility, and of extensibility. Elasticity is the property which a substance possesses of returning to its original size when the cause that distends it ceases to operate. The operation of this property is of great importance and extent in the animal economy, and it is peculiar to the cellular tissue. There is reason to believe that no other texture possesses it in the slightest degree, but in so far as this substance enters as a constituent element into its composition. Although elasticity can never be the source of power; although it cannot originate motion; although it can only restore, in a contrary direction, the force which had been impressed by some other agent, yet, in the various functions of life, its action is exceedingly extensive and important. The arrangement by which this is secured is extremely beautiful. The tissue in which this property is inherent is so disposed throughout the body, that it is kept in a state of constant distension, both by its situation and by its connexions. As long as the distending cause continues to operate, the elastic property has no action; but whenever the circumstances that distend it vary, that moment its elasticity comes into play; and these circumstances vary almost every instant. Whenever the extremities of any portion of the tissue, in any part of the body, are brought nearer to one another; whenever the contents of any hollow organ are withdrawn; whenever any such hollow body is divided transversely, that instant it contracts or shrinks, and thus a power is obtained in the economy. The cartilages of the

* See an unpublished pamphlet by Mr. R. Brown, V. P. L. S.

ribs are endowed with a high degree of elasticity: the arteries possess this property in a still greater degree: it will hereafter be shown, that in the functions of respiration, and of the circulation, its use is so great, that these important actions could not possibly go on without it. The situation and action of the epiglottis afford another striking and beautiful illustration of the use to which it is applied. The windpipe, the tube which conveys air to the lungs, being placed before the œsophagus, the tube which transmits the food into the stomach, the food, in order to get into the latter organ, must necessarily pass over the former. But it is essential to the function of respiration that air should be constantly passing to the lungs: an interruption to its transmission, for any considerable time, would stop the process and destroy life; and yet the opening into the tube which is to convey the air must, necessarily, be closed every time a morsel of food or a drop of water is swallowed. How is this aperture invariably and instantly to be closed just at the moment when its closure is required, and yet to remain open at every other period? A cartilage is placed at the top of the windpipe, attached to the root of the tongue: the tongue, in the act of deglutition, necessarily passes backwards, but it cannot pass backward, without pushing the cartilage over the aperture so as completely to close it. As soon as the tongue ceases to press upon the cartilage, in consequence of the high degree of elasticity with which the latter organ is endowed, it springs up of its own accord, and so leaves the aperture open. That aperture requires to be closed only during the moment we swallow: its closure is secured by the act of deglutition; it requires to be open at every other period; it is kept open by the elasticity of its lid.

Such are the properties of the cellular tissue. As this tissue forms the basis of every organized solid, so the properties with which it is endowed are the most simple, that is, they belong to many other natural objects. Cohesion must, of course, be possessed by every solid substance. Extensibility, flexibility, elasticity, are found in vegetable, mineral, and in dead animal matter. These properties are entirely physical. They are connected with the peculiar arrangement of the particles and the chemical composition of the substances in which

they reside. All the effects they produce in the animal economy are totally independent of any vital action.

2. But the second primitive tissue, the muscular, is the seat of a power properly vital. To the muscular fibre, considered as a compound of muscle and membrane, belong all the properties of cellular tissue: to pure muscle is attached only one property, which is termed contractility; and this is peculiar to it, and is truly a vital power. As it actually exists in the body, then, muscle possesses two classes of properties, physical and vital. It owes its physical properties for the most part, but especially its elasticity, to the cellular tissue with which it is combined. Cohesion, flexibility and extensibility must belong, indeed, in some degree, to its own substance; but these are of little consequence compared with its peculiar and specific property of contractility. Contractility is the property which the muscular fibre possesses of shortening itself. It is the generator of power. It is not only not a mechanical property, but it possesses nothing in the slightest degree analogous to any mechanical force. In the best contrived machinery there is no real generation of power: there is merely an application of pre-existing power to some specific object. In the reaction of an elastic body, in the recoil of a spring, there appears to be an actual production of power; but the effect thus apparently produced is the mere reaction of the force originally employed in compressing the spring. The force of the recoil can never be greater than the force employed to compress it, and the moment this power is expended, all capacity of motion is at an end. In muscular contraction, on the contrary, there is a real generation of power. If, in an animal recently killed, the interior surface of the ventricle of the heart be pricked gently with a needle, the ventricle will instantly contract with such force as to propel the needle deeply into its substance. The force of the contraction of the ventricle in this instance must be incomparably greater than the force with which it is pricked by the needle. There is, thus, an actual production of power, because the effect bears no proportion to its mechanical cause. There is, then, not only no identity, but no analogy between this power and any of the great principles of nature, which are original sources of mechanical force. And of this the complete

proof is, that its most powerful effects are produced without the intervention of any mechanical cause,—by an agent which has no relation to any physical property of matter, namely, by volition. This power, therefore, is distinct from any other in nature, and is peculiar to life. The phenomena of muscular contraction, and the laws which regulate it, will be described hereafter.

3. To the nervous tissue, besides those that are merely physical, belong two distinct and peculiar properties; and these also are vital: they are denominated the nervous and the sensorial. The nervous power consists of a property resident in the nerves, upon which the following phenomena depend:—

1. The transmission of the stimulus of volition to the voluntary muscles.
2. The transmission of impressions received from the external senses to the spinal cord and the brain.
3. The exertion of a certain action upon the blood, by which are maintained the secreting and the other assimilating processes, in which the preservation of the structure of the different organs depends.
4. The exertion of an analogous action upon the blood, by which a disengagement of caloric is produced, and the temperature necessary to animal life and health sustained. The sensorial power consists of the faculty of sensation, that is, sensation attended with consciousness or perception, of volition, and of the faculties termed intellectual. For reasons hereafter to be assigned, it is certain that the nervous and the sensorial are distinct and independent powers, and these phenomena will be further described in the proper place.

From the exposition that has been given of the properties of the primitive tissues of the body, a little reflection will show that it is possible to deduce four distinct powers to which we may refer the particular events or phenomena which, taken together, constitute, or, at least, which are invariably found, only in connexion with life. These general powers, to which distinct classes of phenomena may be referred, are—organic affinity, contractility, nervous power, and sensorial power.

1. To the first, organic affinity, are referable the phenomena of production, secretion, growth, and the various processes by which the different structures that compose the animal fabric are modelled. The power by which these effects are produced is common not only

to all animal but to all vegetable bodies—it may be considered as the common property of organized beings—it appears to be the immediate result of that peculiar arrangement of parts which is termed organization: it is, therefore, appropriately termed organic, and the principle considered abstractedly may be denominated organic affinity, in contradistinction to the ordinary chemical affinities to which it is so often opposed.

2. The second general power to which vital phenomena may be referred, is contractility. With the exception of that which depends on the physical property of elasticity, it is the source of all the motion which takes place in the animal system. In all the higher animals it resides in the muscular tissue alone: in the lower, in which there appears to be no distinction of tissue, it belongs to the homogeneous substance of which the body is composed.

3. The third general power to which particular classes of phenomena may be referred is the nervous. By this power impressions are received from certain parts of the nervous system, and communicated to other parts of it; impressions are also received from the external world, and conveyed to particular parts of the same system; it is, therefore, by this power that the animal is connected with the external world; and it also exerts, as has been shown, a very important influence over certain actions which are indispensable to animal existence.

4. The fourth general power, the sensorial, is that to which we must refer the important faculties already enumerated, namely, perception, volition, and those which are termed intellectual. By these faculties the animal is capable of enjoyment: they do not so much constitute his being—they do not so much contribute to the maintenance of existence, although existence can be prolonged only a few moments after their operation has ceased, as to the rendering existence a good. They are the final cause for which all the other faculties exist, because they are the ultimate end for which the animal itself lives. Thus, the nervous and the muscular powers are those by which the life of the animal is preserved, and by which it affects and is affected by the external world: the sensorial are the powers by which the ultimate end of its being is attained: it follows that the final cause of the nervous and the muscular is the

maintenance of the sensorial powers : accordingly, it is established by direct experiments which we shall detail hereafter, that the muscular is uniformly obedient to the nervous, and the nervous to the sensorial power, while the sensorial power itself is subordinate to the final cause of animal existence—enjoyment.

In the construction of the animal frame, the tissues which have been described are variously combined and modified. Some are disposed in a definite order, and moulded into a peculiar form : others are disposed in another order, and moulded into a different form. These definite arrangements constitute organization. Each determinate organization, when moulded into a given form, constitutes what is called an organ. The figure, the magnitude, and the general aspect of the different organs are infinitely various. Their physical properties depend upon the tissues of which they are composed, and upon the modifications which those tissues undergo. Their chemical properties depend upon those of the tissues, and of the fluids. Their vital properties are peculiar and specific. Every individual organ is endowed with the power of performing a specific action : the performance of that action is the sole object and end of its existence, and that action, whatever it be, is termed its function. Thus every organ is an instrument, and as life consists in a series of actions, performed by different organs, the latter are termed, as has been stated, the instruments of life. And that this organic power is connected with organization, is inferred from the fact, that the effects produced by different organs invariably correspond with the particular arrangement of their elementary tissues, that is, with their peculiar organization. The stomach never possesses the power of secreting bile : the liver never secretes the gastric fluid : the peculiar organization of a part is essential to, and secures its peculiar action.

Thus it appears that every individual organ is the seat of some special function. A function consists of certain phenomena, which have a peculiar relation to each other, and which concur in the production of a definite object. These phenomena occur in a series : the succession of each phenomenon in the series is definite and fixed. Thus, the function of respiration consists, first,

of the motion of the muscles, which raise the ribs and depress the diaphragm ; secondly, of an increase in the cavity of the cells of the lungs ; thirdly, of an ingress of atmospherical air into those cells ; fourthly, of certain changes produced in the quality of the blood during its passage through the lungs, and so on. In this instance each phenomenon follows in a certain order, and the whole concur in the production of a definite object ; and the same is true of every function of every living being.

Since life consists in a series of actions performed by different organs, it is obvious that the main object of physiology must be to give an account of these actions or functions. In order to execute this task with advantage, it is necessary to adopt some classification of the functions, and a simple and natural arrangement is very important. On examining carefully the circle of actions performed by the living being, we observe that these actions have for their object the preservation of the individual, the reproduction of the species, and the bringing the individual into communication with other beings. The first class of functions comprehend those of nutrition ; the second, those of reproduction, and the third those of relation. The function of nutrition consists of the following processes :—digestion, circulation, respiration, secretion, absorption, and excretion. The function of reproduction comprehends the different processes of generation. The function of relation comprehends locomotion—the nervous influence ; sensation, the particular senses and the intellectual faculties ; voice, speech, and so on. Of these functions we shall treat pretty much in the order enumerated, beginning with the process of digestion, and describing the blood, which it is the great object of this process to form.

Of Digestion.

We have seen that one of the essential characters of a living being is the power it possesses of resisting within a certain range the ordinary influence of physical agents, and of maintaining its integrity under circumstances in which it would be decomposed were it destitute of a vital principle. These vital phenomena are effected by the establishment of a circle of actions in the interior of the living body, by which its integrant

particles are maintained in a state of alternate decay and renovation; its old particles being continually removed, and new particles being deposited in their place. The activity with which this interchange is carried on varies in every different individual, and in the same individual at different periods of its life; but the rapidity with which certain processes are accomplished would seem to show that that interchange cannot be slow. Hales ascertained by direct experiment, that a sunflower, weighing three pounds, exhaled twenty-two ounces in the space of twenty-four hours, that is, nearly half its weight: and by a series of experiments, Reil ascertained that, in his own person, he lost by the process of perspiration thirty-one ounces in twenty-four hours. Attempts have been made to calculate the space of time in which every particle existing in the human body at any given period would be removed and replaced by new matter, and a notion has prevailed that a complete and entire change is effected in the course of seven years: but this is mere conjecture.

From the continual removal of the old, and the corresponding deposition of new particles, a source must be provided for furnishing the body with a supply of fresh materials. That source is the aliment: but the aliment as it is received by the living body is always a compound, often an exceedingly heterogeneous substance; while it is an ascertained law that no food can contribute to the support of the body unless it be decomposed and resolved into its primitive elements. In order to accomplish this resolution of the alimentary matter, a certain process is established, in some cases simple, in others extremely complicated. The process itself is termed, in the vegetable, nutrition; in the animal, digestion; and the organs by which it is accomplished, constitute, in the former, the nutritive; and, in the latter, the digestive, apparatus. There is an invariable relation between the simplicity or complexity of the apparatus and the simplicity or complexity of the process; and also between the complexity of the process and the elevation of the individual in the scale of being.

The simplest case of nutrition is found, where the physiologist might have expected to find it, in the most simply constructed vegetable. In plants, in general, indeed, this process is much more simple than it is in the animal,

and it would seem to be one office of this great division of organic being to perform the transformation of dead matter into living substance. For it is the part of the plant to act upon inorganic matter: to derive its nourishment from earths, salts, airs, compound substances which it decomposes, and the elements of which recombining anew, it assimilates into its own proper nature. On the contrary, the animal in general operates either upon vegetable or animal substance. The elements of the mineral kingdom would seem to be too remote from the nature of the animal, to be capable of being converted into its substance, unless previously elaborated by the vegetable. By its nutritive organs the plant acts upon and assimilates inorganic matter: by its digestive organs the animal acts upon and assimilates organic matter already organized by the vegetable. Hence plants may be considered as the great laboratory in which Nature prepares food for animals, and thus exhibits a mutual relation and dependence between the mineral, the vegetable, and the animal kingdoms, truly harmonious and beautiful. Still, however, this representation must be considered only as generally, and by no means as universally true: for plants are not nourished exclusively from mineral substances, nor are animals nourished exclusively from vegetable matter.

It has just been stated that the simplest case of nutrition is found in the most simply constructed plant. Such, for example, are the fuci, many tribes of which without any root, without any special organ of any kind, derive their nourishment from air and moisture alone. A very elegant example of this extreme simplicity of structure and function is afforded by the ærial epidendrum, a beautiful plant, a native of Java, and of the East Indies, beyond the Ganges. In the latter region it is stated to be not uncommon for the inhabitants to pluck it up on account of the elegance of its leaves, the beauty of its flower, and the exquisite odour it diffuses, and to suspend it by a silken cord from the ceilings of their rooms, where, from year to year, it continues to put forth new leaves, new blossoms, and new fragrance, excited to new life and action only by the stimulus of the surrounding atmosphere. Similar examples are furnished by some of the most succulent plants of the hot cli-

mates, which, though they are indeed provided with a root, yet, according to the opinion of the ablest physiologists, this organ is not to them an instrument of nutrition: on the contrary, it is conceived that these plants thrust their root into the earth merely for the purpose of supporting themselves in an erect position, because they are capable of growing only in soils or sands so extremely arid, that no moisture can possibly be extracted from them; and they quickly perish if they are exposed to wet, or to a rainy season. In all these cases nutrition is effected by the common substance of which the plant is composed, and the materials from which it is derived are air and the moisture suspended in it. Such plants may be considered as placed on the very confines of organized existence, and as transmuting in the simplest possible manner inorganic matter into living substance.

The first advancement from this, the lowest point of organization, is found in the more perfect plants. In all these the organ of nutrition is the root. Every other part of such plants may be destroyed, but if the root remain uninjured the plant will regeminate; while, if the root perish, the plant is irrecoverably lost. Such plants require for their sustenance other substances besides air and moisture: their nutrient matter being of a more heterogeneous nature, demands a more complicated apparatus for producing the necessary changes. The root forms that apparatus, and is thus a special organ, provided for the purpose of nutrition; and, in a physiological point of view, may be considered as the first advancement in complication of structure, and in corresponding complication of function.

In the organization of the simplest animals there is no appreciable advancement in structure, although they unquestionably perform additional functions. The very lowest animal probably enjoys some degree of sensation, and there can be no question that it possesses the power of spontaneous motion. Yet it appears to perform the function of nutrition in a manner perfectly analogous to that of the simplest plant. In studying the organization of living creatures, we observe, without doubt, traces of a graduated scale of being: but either the graduation of the scale is not perfect, or we are ignorant of many of the degrees that must be marked upon it; either the chain is defective, or some of its

links are unknown to us. Thus the creatures placed at the bottom of the animal scale seem to possess even a less complicated structure than the perfect plant. These simple beings form the curious class of animated creatures termed the *infusoria*. When dead vegetable or animal matter has been kept for some time in a state of maceration in water, in a moderately warm temperature, the fluid is found to swarm with living creatures. Because these beings appear to be produced by the infusion in water of vegetable or animal substances, they have received the name of *infusoria*. Their extreme minuteness places them beyond the cognizance of unassisted sense, and we owe our knowledge even of their existence to the microscope. Of these creatures, the minutest and the simplest is a transparent globule, having the form of a point (*fig. 13*), which, because it is conceived to be placed at the ultimate limit of animal existence, is called by Muller the *monas termo*. All naturalists are agreed that this minute point is an

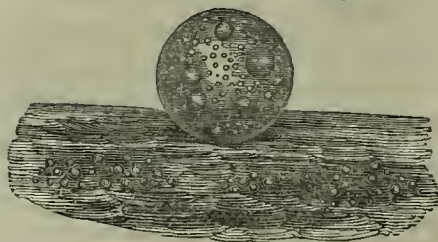
organized being of an animal nature. The inference that it is an animal is founded on its motion, which has all the appearance of being spontaneous, and which, in the actual state of our knowledge, certainly cannot be referred to any external physical cause, or to any chemical agency. It seems scarcely possible to contemplate its movements for any considerable time without being satisfied that it is truly spontaneous. All who have made a particular study of minute animals have considered it as belonging to this class of beings; and Cuvier has placed it at the bottom of his Animal Kingdom, or at the commencement of the animal scale. It is found not only in infusions of vegetable and animal matter, artificially prepared, but, when the temperature is mild, in stagnant waters, whether salt or fresh. It seems to be a vesicle, or to consist of a delicate membrane inclosing a transparent fluid: hence it is described by Professor Carus as a living animal cellule. If it be difficult, on account of its extreme minuteness, to ascertain its structure with exactness, it is quite certain that animalculi of precisely the same figure and appearance, but of a larger size, and which seem to consist of a congeries of these minuter beings, are vesicular. In these larger creatures, the membrane forming

Fig. 13.



the external envelop of their body can be distinguished from the fluid contained within, and in that fluid can be perceived numerous globules of a smaller size, apparently vesicular also. This is extremely well seen in the *Volvox Globator* (fig. 14).

Fig. 14.



Now in this, the lowest class of animals, the function of nutrition is performed in the simplest manner, and is perfectly analogous to that in the vegetable. Their nutritive matter is received by imbibition through the parietes of their external membrane, without any mouth, and without any apparatus for digestion that can be distinguished.

The first advancement from this simple condition of animal existence is observed in a higher tribe of animalculi, and also in the lowest order of polypes. It consists of a membranous sac open at one extremity (fig. 15). The figure of the

Fig. 15.



animalcule is that of a purse, which has given name to the tribe denominated *Bursariæ* (fig. 15.) The figure of the polype is very similar to that of the flower termed *Campanula*, and it is therefore called bell-shaped. The inhabitants of coralline and sponge are constructed essentially in this manner. Instead of a membrane inclosing a cavity without any aperture, they consist of a membranous cavity open at one extremity. This conformation affords the first and the simplest conceivable rudiment of an alimentary canal: the whole internal surface of the animal must be considered as forming one extended stomach, and hence the animal

has been described by Cuvier, as being a sentient self-moving sac capable of digesting food. In the higher tribes of this order, processes or lashes are arranged around the external margin of this aperture (figs. 16, 17, 18), which are

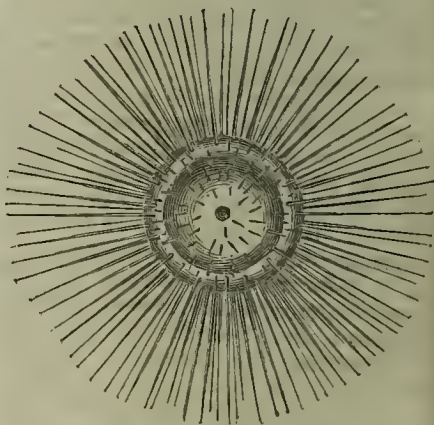
Fig. 16.



Fig. 17.



Fig. 18.



This figure represents the mouth of one of these creatures, very highly magnified.

endowed with the power of motion, and by means of which the fluid in which the animal swims, and which contains its aliment, is propelled into its rudimentary digestive canal. In the tribes placed above these, the aperture leading to this internal cavity is not always open, but is capable of alternate contraction and expansion, thus exhibiting the first and the most simple form of a mouth.

It has been stated, that in the more perfect plants the root is the organ by which the function of nutrition is performed, and that if the root be injured, the plant inevitably perishes. Yet there are species of plants in which the trunk can be made to perform the office of the root, and the root that of the trunk. In the *prunus* and *salix*, the cherry and

willow tribes, if the stem branches be bent down to the earth, plunged into it, and continued in this situation for a few months, these branches will generate radicles, which will perform the proper functions of the root. If, subsequently, the original root be dug up and suffered to ascend into the air, so that the whole plant shall become completely inverted, the original root will throw forth stem branches, and will bear the wild fruit peculiar to its tribe. The *rhizophora mangle*, or mangrove tree, grows naturally in this manner; for its stem branches, having reached a certain perpendicular height, bend downwards of their own accord, and throw forth root-branches into the soil, from which new trunks arise, so that it is not uncommon, in some parts of Asia and Africa, to meet with a single tree of this species covering the oozy waters in which it grows with a forest of half a mile in length. The *figus Indica*, or banyan, grows in the same manner, and often with enormous trunks, equally derived from a primary root. Precisely analogous is the curious property possessed by the *Bursariæ* and the *Polypi*. If these animals be inverted or turned completely inside out, that surface which was naturally external performs the office of the internal perfectly, and the process of nutrition is carried on without the slightest apparent inconvenience or change. As we ascend in the scale of being, however, these vicarious offices cease to be performed: a specific organ is provided for every particular function: the function can be executed only by its own proper organ, and if the organ be destroyed or injured the animal perishes.

Tracing, in the ascending scale, the successive advancement of structure in these simple beings, after an animal possessing an internal cavity, either with the aperture always open, or with the power of contracting or expanding the mouth of the opening, we next come to a complication which is exceedingly important. It consists of a distinct membranous tube included in an external envelop, the external envelop forming what may be properly termed a body, and the internal tube affording the first rudiment of a stomach, or rather the first indication of a special digestive organ. The animals termed *vorticellæ* are constructed in this manner, and it has been lately conceived that the *vibrio* of paste possesses an analogous struc-

ture (*fig. 19*). In the next order of zoophytes we meet with a mouth which is very distinctly formed, and which in most cases is surrounded with numerous tentaculi. The mouth opens into a

Fig. 19



shut sac or stomach, which is perfectly distinct from the mass of the body. The stomach rejects its excrementitious matter by the same passage that admits its aliment, so that one common aperture serves both for mouth and anus. In the *medusa* all these points are well seen. On the inferior surface of the body there is a simple aperture, or mouth, for the purpose of suction. Its cavity leads by four apertures into a like number of sacs or stomachs excavated in the gelatinous substance of the body. And these stomachs, in a manner almost inconceivable, are capable of digesting hard substances, and especially the small prickly fishes upon which they prey.

In the *echinodermata*, the highest order of zoophytes, there is a further and a very important advancement in organization. In the *asterias*, or star-fish, the stomach is not only quite distinct from the general mass of the body, but the entrance to it is surrounded by teeth, which are generally five in number (*fig. 20*). These animals afford the

Fig. 20.



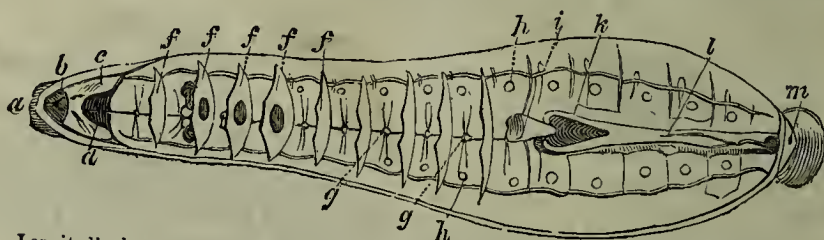
first trace of distinct organs of mastication. With these teeth they seize upon small fish and other minute animals, on which they prey; for these, and almost all the lower orders of creatures, live upon animal matter. In the *echinus*, or sea-hedgehog, the organs of mastication are still more developed.

Ascending considerably in the scale,

we come to the *articulata*, in which the organs of digestion are very much more perfect. As an example of the structure of this class, we may take the leech, an animal familiar to every one. The

mouth of the leech is of a triangular figure. It is furnished with little sharp edges for the purpose of dividing the skin (*fig. 21.*) Attached to the mouth is a strong fleshy pharynx, which is the

Fig. 21.



Longitudinal section of a Leech; *a*, sucking surface of the mouth; *b*, cavity of the mouth opened, with a view of its triangular aperture; *c*, muscles of the pharynx; *d*, cavity of the pharynx; *f*, perforated septum of the stomach; *g*, chain of ganglia; *h*, respiratory vesicles; *i*, lateral vessel; *h*, pylorus; *l*, commencement of the intestine; *m*, anus.

principal agent in sucking blood. Next to this follows a long and capacious stomach, consisting of a membranous bag, divided by several septa into large cells, which communicate with each other by oval apertures. Somewhat more than midway down the body, the intestine arises from this extended stomach: it commences by a small funnel-shaped valvular opening, and terminates in a minute anus placed at the superior edge of the posterior disc. But though provided with an anus, it more frequently discharges its excrementitious matter from the mouth than through its narrow intestine, and thus it forms a kind of link between the inferior and the higher stages of organization.

We shall advert to but one order more in the ascending scale—the *crustacea*. In this order, as in the crab, the lobster, the prawn, we find, for the first time, the organs of mastication fully and completely formed; we have jaws, properly so called (*fig. 22, 23*). Nor should we overlook the singular stomach with which they are provided: few things in animal structure are more curious: it is formed on a bony apparatus, to certain parts of

Fig. 23.

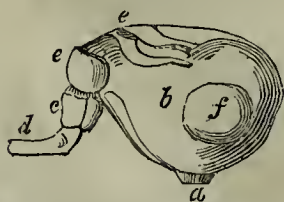


The same opened from the oesophagus length ways, and at the lower part; *a*, great central teeth of the stomach; *b, b*, two large lateral teeth; *c, c*, two small lateral teeth; *d*, bony lamina on the anterior and larger or cardiac portion of the stomach; *e*, the smaller or pyloric portion of the stomach; *f*, entrance to the intestine.

which around the pylorus the teeth are affixed, which are moved by distinct muscles, and so arranged that nothing can pass the pylorus without being completely comminuted.

Brief and imperfect as the preceding sketch must appear, yet it may suffice to convey to the reader a general idea of the progressive advancement which may be traced in the structure of the digestive organs from the lowest to the more perfectly organized animal. And, in fact, at the point at which we have now arrived, we recognize every essential part of the digestive apparatus, which is to be found in the highest animal. We have organs for apprehension, for mastication, for deglutition, for digestion, for excretion: we have a mouth, teeth, jaws, a pharynx, a stomach and intestines. In a physiological view, therefore, more especially considering the brevity which must be observed in

Fig. 22.



Stomach of the Crab viewed externally; *a*, oesophagus; *b*, fundus of the stomach; *c*, pylorus; *d*, intestine; *e*, skeleton of stomach; *f*, stony concretion.

this treatise, it is unnecessary to trace the complication further.

In all the higher animals the function of digestion consists of four distinct acts, namely, mastication, deglutition, chymification, and chylification; to which must be added the process of excretion. We shall first of all describe, very briefly, the apparatus by which these actions are performed; and, secondly, consider the actions themselves.

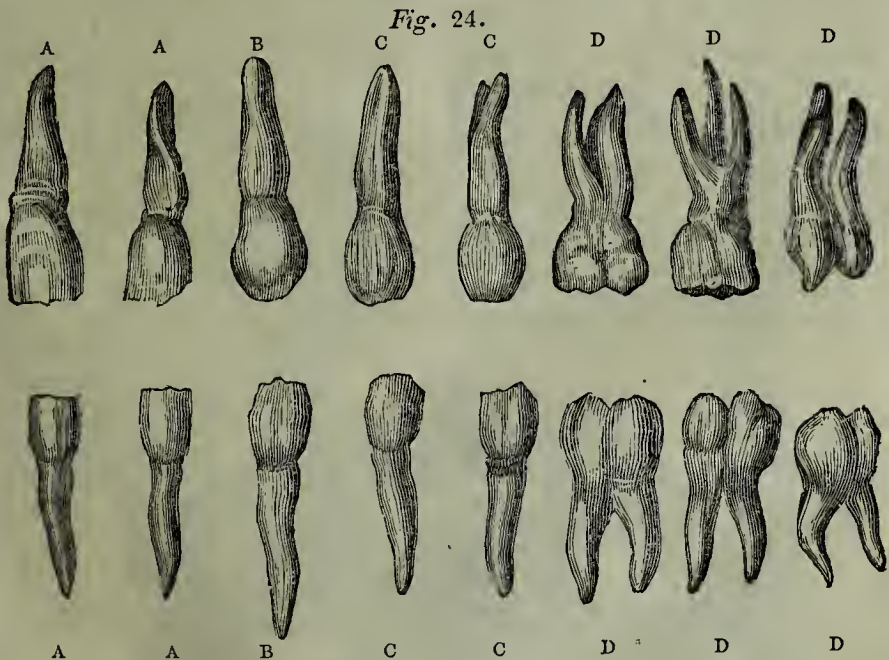
1.—Of the Organs of Mastication.

Mastication is essential to digestion. Its object is minutely to divide the food. In all animals furnished with distinct digestive organs, expedients are provided for accomplishing this purpose. These expedients are varied according to the kind of food on which the animal subsists, and according to the general organization of the body. They consist, for the most part, of a mouth, of teeth, of jaws furnished with powerful muscles to act upon them, of the tongue, and of the salivary glands.

The mouth, consisting principally of the lips, and, in the view we are now taking of the organ, of the cheeks also, is formed of numerous muscles which are capable of the utmost complexity and diversity of action. The form and situation of the teeth, as well as of the

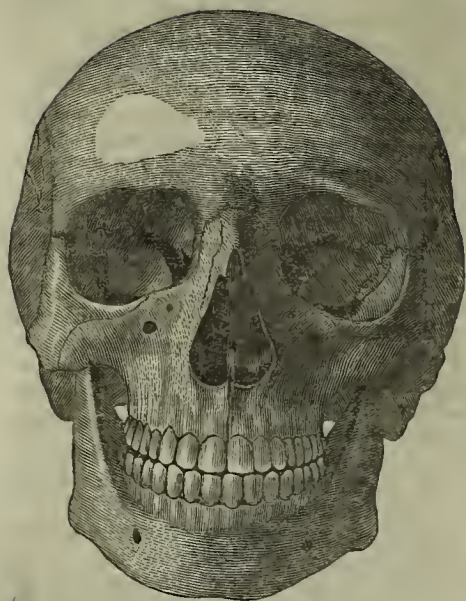
jaws which contain them, are extremely varied; and so strictly are these diversities connected with the peculiar habits of the animal, with the species of alimentary matter on which it lives, and with the general organization of its body, that naturalists assume these organs as affording the most clear and certain characters on which to found the basis of their systematic classifications.

Some animals live entirely on vegetable, others wholly on animal matter, and to the health and vigour of others a mixture of both is necessary. These differences in the habits of animals require a corresponding modification of the organs of mastication, and especially of the teeth and jaws. The differences observable in the configuration of the teeth have led anatomists to divide them into separate classes. Those situated in the front of the jaw are called incisores, or cutting teeth (*fig. 24*): these bodies are wedge-shaped (A A). Placed at the sides of the incisores are the cuspidati or the canine teeth (B B): the bodies of these, also, are in the shape of wedges. Immediately behind the cuspidati are the bicuspidati, or the first and second grinders (C C); and the largest of the teeth, placed the most posteriorly, are called the molares, or the grinders (D D). In every different



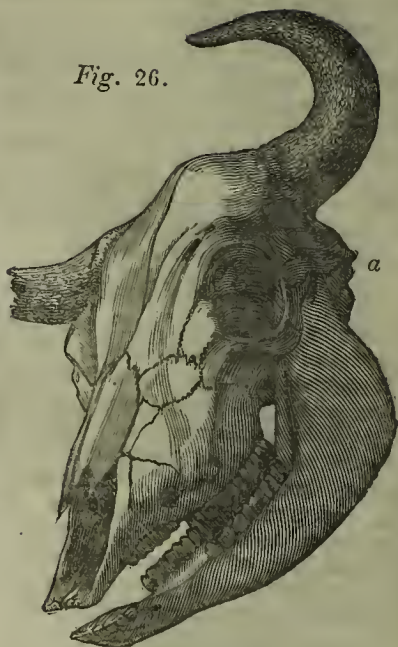
Upper and lower teeth of the left side of the jaw: A, A, A, A, the incisores; B, B, the cuspidati or canine teeth; C, C, C, C, the bicuspidati, or first and second grinders; D, D, D, D, D, D, the molares, or grinders.

Fig. 25.



Front view of the Skull, with the teeth in their natural situations.

Fig. 26.



Skull of the Cow.

class of animals these teeth vary in strict accordance with the diversity of food on which they subsist. Thus in the graminivorous quadruped the molares are large and broad. Their magnitude, indeed, is so great as absolutely to require that the jaw should be much elongated, in order to make room for them (*fig. 26*). The condyles of the lower jaw (*a*), or those extremities by which the lower is united with the upper jaw, are rounded, in order that the lower may move upon the upper jaw with the utmost freedom in every direction, but especially laterally. This lateral motion is indispensable to the action called grinding, an action peculiarly adapted for the comminution

of the substances upon which these animals feed. It is worthy of remark, that in the horse, which crops the herbage by snapping it crosswise, there is this further modification of the teeth, that the incisores have broad cutting edges, which meet like the blades of pincers, the precise conformation needed.

The structure of the teeth, and the general figure of the jaw in carnivorous quadrupeds, presents a striking contrast (*fig. 27*). In this class the molares are comparatively small (*fig. 24*), at the same time they are much more pointed. On the other hand the cuspidati are remarkably large (*fig. 24*), and the incisores in general are quite pointed (*fig. 24*). The jaws themselves

Fig. 27.



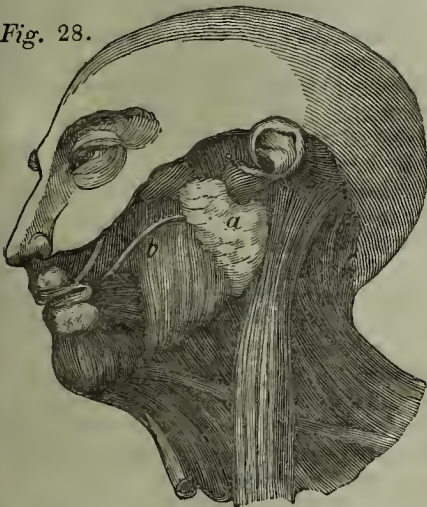
Skull of the North Polar Bear.

are short (*fig. 27, a*). Their condyles are so locked in by the fore and back parts of their articular cavities, that any degree of lateral or rotatory motion is prevented (*fig. 27, b*); the jaw can move only in a vertical direction, or is capable only of elevation and depression. All this arrangement, it is obvious, is adapted for lacerating and cutting the animal fibre. Living entirely upon flesh, these animals do not need a grinding motion of the jaw, but they require a powerful cutting instrument: hence their small and sharp molares; their large cuspidati; their pointed incisores, and the prodigious power of the muscles by which the teeth of their lower are closed upon those of their upper jaw. The most superficial examination of the human teeth shows that they hold a middle place between those of herbivorous and carnivorous animals. (*fig. 25*).

The tongue is a very important organ both of mastication and of deglutition; it consists almost entirely of muscular substance, covered by mucous membrane. Its fibres are variously arranged, and are very intimately connected together, so as to render it capable of motion in every conceivable direction, a structure admirably adapted for conveying the food wherever it may be necessary to be acted upon by the teeth.

Among the organs which are essential to the process of mastication, must be reckoned the salivary glands (*fig. 28*).

Fig. 28.



a, Parotid gland; *b*, duct for conveying the saliva into the mouth.

These bodies convey to the mouth the saliva they secrete, by numerous ducts which open into it. In man the chief salivary

glands are three on each side (*fig. 28*); the parotid, situated on the cheek; the submaxillary, situated beneath the lower jaw; and the sublingual, situated beneath the anterior portion of the tongue. These glands pour into the mouth a large quantity of fluid; it is estimated that they afford about eight ounces of fluid, which is mixed with the food at each meal.

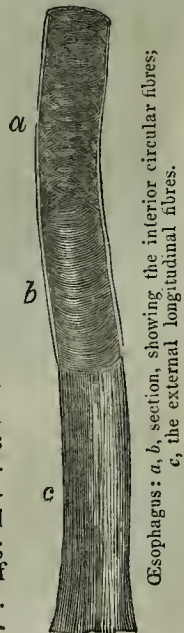
2.—Of the Organs of Deglutition.

The organs of deglutition are the tongue, the pharynx, and the œsophagus. The tongue has been already described; its posterior portion or base is connected, through the medium of the arches of the palate, with the organ termed the pharynx. The pharynx, so called from its conveying food to the stomach, and air to the lungs, is a large muscular bag, having the form of an irregular funnel, the large opening of the funnel looking towards the mouth, while the under and smaller end of it constitutes the tube which leads to the stomach, termed the œsophagus. The muscles which compose the pharynx, and with which it is connected, are capable of raising or elevating it, that is, of bringing it nearer the base of the tongue; of depressing it or carrying it from the base of the tongue, and of causing it to contract upon itself, that is, of narrowing its calibre.

The œsophagus, called also the gullet, derives its name

from its office of conducting the food into the stomach. It is a fleshy tube which begins from the inferior part of the pharynx (*fig. 29*), descends along the neck, passes through the thorax, and terminates in the stomach (*fig. 30*). It consists of three coats or three membranous coverings, which are perfectly distinct from each other: the first is composed principally of cellular substance; the second of muscular fibre; and the third of mucous membrane. The second or mus-

Fig. 29.

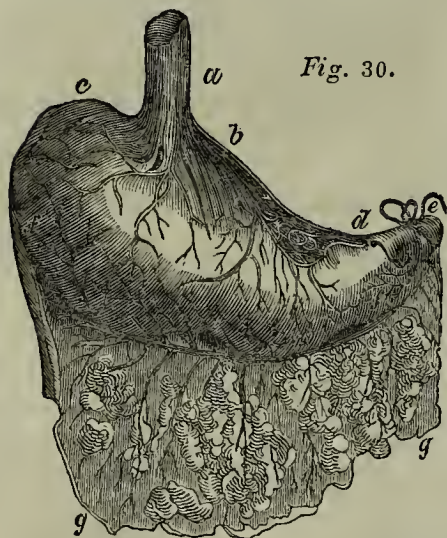


Œsophagus: *a*, *b*, section, showing the interior circular fibres; *c*, the external longitudinal fibres.

cular coat consists of two layers of fibres; all the fibres which form the external layer have a longitudinal direction; all those which form the internal layer are circular. The function performed by this tube requires that it should possess two kinds of motion, that of shortening itself, and of lessening its diameter. It is obvious that the contraction of its longitudinal fibres will shorten it, and that a contraction of its circular fibres will narrow it. The inner or mucous coat is continued from the lining of the mouth; it is formed into numerous longitudinal folds, which expand so as to become scarcely visible when the œsophagus is dilated, and it is always abundantly lubricated with a mucous fluid.

3.—Of the Organ of Chymification.

The process termed chymification is performed by the stomach. The stomach is a large membranous bag situated obliquely across the upper part of the abdomen (*fig. 30*). Its figure has been



The Stomach: *a*, œsophagus; *b*, cardiac portion; *c*, great or left extremity; *d*, small extremity; *e*, stomach tied at the pylorus; *f*, great anterior curvature; *g*, omentum.

not unaptly compared to that of the bag of a bag-pipe. It is capable of holding in the adult man, when moderately distended, about three pints. It has two extremities (*fig. 30, c, d*), two curvatures (*fig. 30, f, b, d*), two orifices (*fig. 30, a, e*), and three coats.

The large extremity is situated on the left side of the body (*fig. 30, e*), the stomach gradually diminishes in bulk towards the small extremity which is situated on the right side. The inferior border of the stomach, which is convex, is termed the great curvature, or arch (*fig. 30, f*); the superior border, which is also convex, is named the lesser curvature, or arch (*fig. 30, b, d*). The two orifices or openings of the stomach, are situated in the lesser arch (*fig. 30, a, e*). The left (*fig. 30, a*) is formed by the termination of the œsophagus, and is therefore termed the œsophageal opening, or the cardiac orifice; the right (*fig. 30, e*) is formed by the termination of the small extremity, and is denominated the pyloric orifice. It is about three inches lower than the œsophageal, and is therefore sometimes termed the inferior orifice.

The structure of the stomach is similar to that of the œsophagus. It possesses three coats, of which the external derived from the lining membrane of the abdomen, termed the peritoneum, is denominated the peritoneal coat. The second coat is composed of muscular fibres, hence it is termed the muscular coat. The fibres consist of two planes, which, like those of the œsophagus, are arranged in different directions. The external plane is longitudinal; it is in fact a continuation of the longitudinal fibres of the œsophagus; it extends from the great to the small extremity, and upon each side of the lesser curvature forms a thick strong muscular band. The second plane is circular; it forms a layer considerably thicker and stronger than the other. It is obvious that the effect of the contraction of the first plane will be to shorten the stomach, or to diminish its length from extremity to extremity; that the effect of the contraction of the second plane will be to narrow its cavity, or to diminish its capacity; and that the result of these alternate or combined actions upon the contents of the organ will be to agitate them gently, to move them in various directions; and since the pyloric orifice is three inches lower than the œsophageal, to direct them ultimately towards the pylorus.

The pylorus consists of a ring of muscular fibres covered with mucous membrane. It is placed, as has been stated, at the lesser extremity of the stomach (*fig. 30, e*). This ring of

fibres form what anatomists term a sphincter, and it is called the Sphincter Pylori (*fig. 39, C*, and *fig. 40*). It completely closes the aperture; and this was necessary, in order that the contents of the stomach might not escape before they had been duly acted upon by the organ: at the same time, however, it was necessary that the orifice should open as soon as the function should be completed. It was requisite, therefore, to construct a valve which should close the aperture as long as was necessary, and which should open of its own accord the moment this contrary action was required. This power of contracting on the application of specific stimuli is one of the most wonderful endowments of living substance: it is a property peculiar to the muscular fibre, and will be fully explained when we treat of muscular action. At present our only object is to point out the admirable use which is made of this property in this particular instance.

The third or inner coat of the stomach is also termed the mucous; it is continued from the inner coat of the œsophagus; but it has more of a velvet appearance, and is more extensive, being folded into numerous doublings, which are termed rugæ (*fig. 31*). It is this

Fig. 31.



A portion of the inner surface of the stomach, shewing the folds formed by the mucous coat, and the velvety appearance it assumes.

membrane which is more immediately connected with those secretions of the organ by which it performs the most important part of its function.

These different coats of the stomach are connected together by exceedingly delicate cellular tissue. Its blood-vessels and nerves are more abundant than those of any other organ of the body: its nerves especially are remarkable, not only for their number, but also for the

variety of the sources whence they are derived. Accordingly, of all the organs of the body, the stomach is the most exquisitely sensitive; it partakes, in a most remarkable manner, of all the general actions of the system; it sympathizes with all the changes in its individual organs; it may be regarded as a kind of common centre, by which all the organic functions are connected together and their motions regulated. For this reason Mr. Hunter called it the centre of sympathies. This adjustment will appear the more beautiful when the extent of the system of the organs and functions concerned in nutrition, and the necessity of providing some means by which their various actions may be connected and combined, are considered.

4.—Of the Organs of Chylification.

The organs of chylification consist of the small intestines, (*fig. 32*), the pancreas, (*fig. 35*) and the liver (*fig. 32, AA*). The small intestines are directly concerned in

Fig. 32.



A, A, the liver raised to shew its under surface; B, the gall-bladder; C, the stomach; D, the situation of the pylorus, and beginning of the duodenum; E, the duodenum making a turn to go across the spine; F, the termination of the ductus communis choledochus in the duodenum; G, the pancreatic duct, terminating in the duodenum at the side of the common biliary duct; H, the continuation of the duodenum; I, I, the cut ends of the great arch of the colon turned aside; K, K, the convolutions of the jejunum and ileum; L, the right kidney.

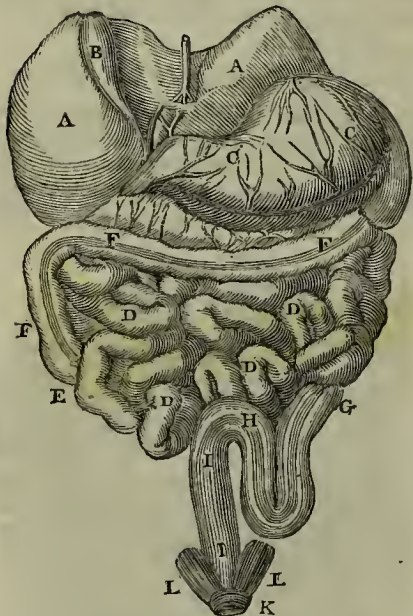
the process ; the pancreas and the liver are only contributory to it. The intestines taken together consist of a long cylindrical canal, which begins at the pyloric orifice of the stomach, and terminates in the anus (*fig. 33*). They are always capacious and long in proportion as the food to be digested is more or less analogous to the substance of the animal it is intended to nourish. In the human adult they are about six times the length of the body : in children, on account of their smaller stature, they are about ten times the length of the body. The intestines are divided into small and large. (*fig. 33*). The small intestines, the

retard the motion of the chyle, in order that it may be more readily and completely absorbed.

Fig. 34.



Fig. 33.



A, A, the liver : B, the gall-bladder : C, C, the stomach ; D, D, D, D, the small intestines ; E, commencement of large intestines in intestine cæcum ; F, F, F, the colon ; G, H, sigmoid flexure of colon ; I, I, rectum ; K, anus surrounded by the sphincter ani ; L, L, two muscles attached to the anus, termed the levatores ani.

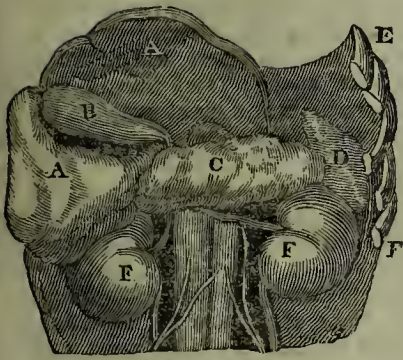
only part of the tube concerned in the process of chylification, are perfectly analogous in structure to the stomach, (*fig. 48*) possessing the same number of coats, which are arranged in the same manner, excepting that the internal or mucous coat is plaited into numerous transverse folds termed *valvulæ conniventes*, (*fig. 34*), the object of which is to extend the surface of the membrane, in order to afford a greater space for the absorbing mouths of the lacteal vessels, and at the same time to perform, in some degree, the function of valves, to

The small intestines are divided into the *duodenum* (*fig. 32, D, E, H*), the *jejunum* and the *ileum* (*fig. 32, K K*). The duodenum is so large as to have received the name of a secondary stomach : it is more firmly fixed to the body than the other intestines ; it does not, like them, float loosely in the abdomen ; its muscular coat is thicker ; its mucous coat presents irregular rugæ in place of *valvulæ conniventes*. At the distance of about three or four fingers breadth from the pylorus, it is perforated by the termination of the pancreatic and the biliary ducts (*fig. 32, F G* ; 49, F), which pour into it the pancreatic juice and the bile. Innumerable mouths of lacteal vessels, hereafter to be described, begin to appear in this organ, for the purpose of absorbing the chyle ; it is here especially that the chyle is formed : the chief use of the jejunum and ileum appears to be to afford space for the distribution of the open mouths of the lacteal vessels by which it is absorbed : hence in these intestines the *valvulæ conniventes* are large, the villi prominent, and the lacteal vessels much more numerous and manifest.

The pancreas is a salivary gland situated in the upper and back part of the abdomen, between the spinal column and the stomach (*fig. 35, C*). Its office is to secrete a peculiar fluid very analogous to saliva, which it pours into the duodenum by a distinct duct (*fig. 49, E E*), at the point already indicated (*fig. 32, G*).

The liver, the largest gland in the body, in like manner secretes a peculiar

Fig. 35.



A, A, the under surface of the liver turned upwards, and to the right side; B, the gall-bladder; C, the pancreas; D, the spleen; E, E, the ribs; F, F, the kidneys.

fluid, termed the bile, which it pours into the duodenum by a distinct duct, called the *ductus communis choledochus* (fig. 49, C, F,) at the same point as that at which the duct of the pancreas penetrates it (fig. 49, F).

5.—Of the Organs of Excretion.

The organs of excretion are the large intestines. (fig. 33, E, F F F, G, H, I.) They are divided into cœcum (fig. 33, G), colon (fig. 33, F F F), and rectum (fig. 33, I I). They have the same general structure as the small. They are divided from the latter by a valve, termed the valve of the colon, which allows a free passage for the contents of the small into the large intestines, but completely prevents their return. This valve is formed by the mucous membrane of the intestine; and the valvular apparatus thus placed at the commencement of the large intestines, points out distinctly that the function performed by these two parts of the canal is essentially different, and indicates with precision the very point where the function of the small intestines ceases and that of the large commences. Without doubt, the great physiological difference between these two portions of the alimentary canal is that the small intestines constitute the organs in which the chyle is formed and absorbed; while the large intestines constitute the organs by which the refuse matter is carried out of the system. Few or no lacteal vessels are found in their entire tract; and in a state of health they are not observed to contain chyle. They are, however, furnished with a considerable number of

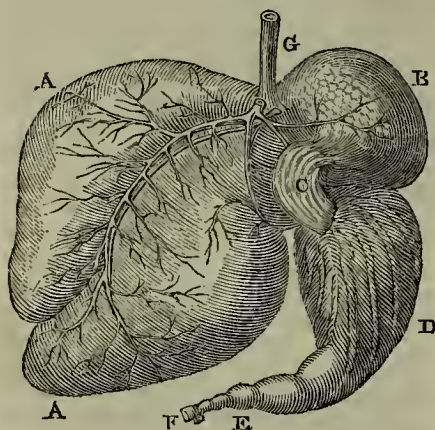
lymphatic vessels which probably absorb the more fluid parts of the fæces, so that nothing that can ultimately contribute to nutrition may be lost. The chief peculiarities of their structure appear to be intended to render the progress of their contents slow; to retain them a considerable time; and, at last, to allow them to be evacuated only at certain intervals, a disposition which a moment's consideration will show to be absolutely essential to the comfort of the animal.

Of the Digestive Apparatus in the Herbivorous Quadruped.

Such are the structure and arrangement of the digestive apparatus in man, and in the animals which most nearly resemble him. In certain animals which live upon particular kinds of food, a part of this apparatus is modified in a very remarkable manner. This is especially the case with the herbivorous quadruped. The modification of the organs of mastication in this class has already been spoken of. The adaptation of the structure and disposition of its stomach and intestines to the food on which it subsists, is equally striking and curious. Living solely upon grass, which contains only a small proportion of nourishment in a large bulk, and which at the same time requires a great deal of mastication, these animals would be absolutely incapable of procuring sufficient nutrient matter, and of preparing it properly for the action of the stomach, without incessant locomotion, were this organ constructed as it is in man. The well-being and ease of the animal is provided for by an exceedingly curious conformation. Taken altogether, the stomach is of prodigious extent in all the tribes of this class. It is divided into four distinct compartments, forming four separate bags (fig. 36): into the first of these, which is termed the paunch, (fig. 36, AA) the food is swallowed, as it is collected, with little mastication. In this bag it is macerated in a considerable quantity of fluid at a moderately high temperature. From the paunch it passes into a smaller bag, called the reticulum (fig. 36, B): from the reticulum it is again returned into the mouth, where it is masticated a second time, and now completely comminuted; and this is the process termed "rumination." In this manner the ruminant animal fills its capacious paunch with nutrient matter after having slightly masticated it; it then betakes itself to

rest, and at its ease returns its food a second time into its mouth in a macerated and softened state, in order to be completely masticated; after this perfect mastication, it is again swallowed: but it does not enter a second time either into the first or the second bag, but passes into the third (*fig. 36, C*), which is called the *omasum*, where it undergoes further and

Fig. 36.



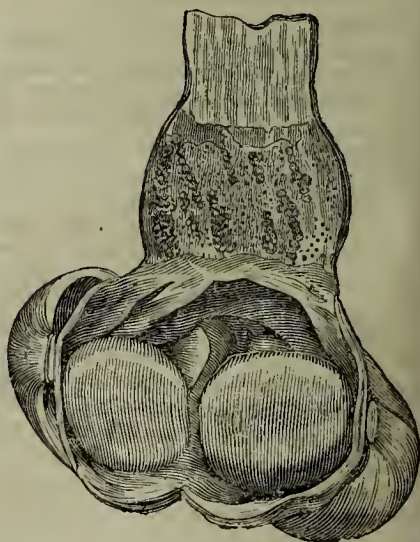
G, the gullet; A, the paunch; B, the reticulum; C, the omasum; D, the abomasum; E, the pylorus; F, the commencement of the small intestines.

specific changes, and from the third it passes into the fourth, (*fig. 36, D*), termed the *abomasum*, which last is perfectly similar both in structure and function to the simple stomach of the other mammalia and of man. It has been already stated that the intestines are always capacious and long in proportion as the food to be digested is less analogous to the substance of the animal it is intended to nourish: thus, in some species of ruminant animals, as in the ram, this tube is twenty-seven times the length of the body, while in carnivorous animals it is short and straight; the food on which they feed being already nearly of their own nature, and containing a large quantity of nourishment in less bulk, a smaller proportion both of time and space are required to fit it for use.

In graminivorous birds there is a still more curious modification of this part of the digestive apparatus. The entire organization of the bird is constructed with a reference to lightness, in order to adapt it for flight. Many birds are carnivorous. In these tribes there was no peculiar difficulty, because their food being already analogous to their own nature, it was only necessary to make

the menstruum by which it is dissolved, powerful and abundant to dispense with mastication altogether, and yet to dispose the stomach and intestines in smaller space; and this is the plan adopted. But a great number of birds live upon vegetable matter, and cannot be brought to subsist on animal food. It was utterly impossible to give to a creature fitted for flight, the enormous stomach and intestines of the herbivorous quadruped. Were the bird furnished with teeth, the general conformation of the class must also be departed from. Thus the bird is to live upon vegetable matter, to be destitute of teeth to masticate its food, and at the same time its stomach and intestines are to occupy only a small compass. How are these different and opposite objects to be effected? They are accomplished by a modification of the digestive apparatus, so simple and yet so effectual, that it cannot be contemplated without admiration. In the first place, the food of the bird, though of a vegetable nature, is not in general grass which contains the smallest proportion of nutritive matter in a given bulk, but grain which contains the largest. Then, in order to obviate the necessity of teeth, to dispense with the process of rumination, and to accomplish the resolution of hard grains and seeds into a soft and pultaceous mass, the following expedient is adopted. In the first place a membranous bag is provided, called the crop or craw, which receives the food from the mouth, slightly softens it by a mucous fluid

Fig. 37.



secreted from its internal surface, and thus prepared, it is transmitted into the organ called the gizzard, one of the most curious structures in the whole animal economy (*fig. 37*). The gizzard is composed of thick and tough muscular substance, small in size, but more powerful in its action than the strongest jaw bone. It consists of four distinct muscles, a large hemispherical pair at the sides, and a small pair at the two ends of the cavity. By their alternate action, these muscles produce two effects; the one a constant friction on the contents of the cavity, the other a pressure upon them. These muscles are lined with a cuticle which is extremely callous, and which often becomes cartilaginous and even horny. The prodigious power with which these muscles act, and the callous nature of the cuticle that lines them, were shown in a striking manner by Reaumur and Spallanzani. These distinguished physiologists in the course of their experiments compelled geese and other birds to swallow needles, lancets, and other hard and pointed substances. In a few hours after the experiment, the birds were killed and examined; the needles and lancets were uniformly found broken off and blunted, without the slightest injury having been sustained by the stomach. Many of these species assist the action of the gizzard upon the food by swallowing pebbles, which in some measure serve the purpose of teeth, and some tribes cannot digest their food without this aid. Mr. Hunter observed that the size of the pebbles is always in proportion to that of the gizzards. In the gizzard of the turkey he counted two hundred: in that of the goose a thousand. The more the student of nature contemplates these modifications, and the more the physiologist succeeds in discovering their use, the more perfect and beautiful the adjustments appear.

Of the Function of Digestion.

The assemblage of organs which has been described, constitutes the apparatus of digestion: their action by which they produce the requisite series of changes upon the aliment constitutes the function.

In expounding this function we shall first consider the changes themselves; and, secondly, the means by which they are effected. Under the first head will be adduced the particular facts, or phenomena of digestion, and under the

second will be given an account of the theories which have been invented to connect and explain them.

Digestion may be defined to be that process by which the aliment is subjected to a certain succession of changes, by means of which it is fitted for nutrition.

Aliment is either solid or fluid; the process for producing the requisite changes in each is considerably different.

Of the Digestion of Solid Aliment.

In the digestion of solid aliment the following changes take place, and in the following order:—The food received by the mouth undergoes a great degree of comminution and softening by the organs of mastication. When thus duly prepared, it is transmitted to the stomach by the act of deglutition. In the stomach it is converted into a uniform and almost fluid mass, which is termed chyme. The chyme passes from the stomach into the first intestine or duodenum (*fig. 32, D, E, H*), in which organ it undergoes a further change. By the action of certain secretions which are here added to it, it is separated into two distinct and exceedingly different substances, one of which is termed chyle and the other *fæcula*. The chyle is the nutritive portion of the aliment, and is conveyed by a particular set of vessels, the structure and the course of which are hereafter to be described, into the blood. The *fæcula* is that portion of the aliment which is not conducive to nourishment, and which is conveyed out of the body. The conversion of the crude aliment into these different substances involves processes of great complexity and obscurity; but the accumulated observations and experiments of physiologists have put us in possession of many curious and important facts relative to the phenomena which take place, and to their order of succession.

Of the Mastication of the Food.

The first part of the digestive process may be considered as entirely mechanical. From the comparative view which has been exhibited of the apparatus for mastication, we learn, that whatever be the structure of the animal, and whatever the nature of the aliment on which it subsists, it is furnished with appropriate organs for the purpose of breaking down or minutely dividing its food. Sometimes this object is accomplished

by mastication; at others by trituration; at others again by a combination of both actions: but whatever be the expedient, the result is uniformly the same—the minute division of the aliment. This preparatory step is analogous to that which is necessary to many chemical combinations. Substances which are capable of exerting on each other the most powerful action, frequently produce no change whatever until the attraction of cohesion is diminished, and at other times not until they are reduced to a softened state. Great care has been taken in all animals to bring the food into both conditions before it is transmitted to the organ in which the proper digestive process is performed. We have seen that in man, the membrane which lines the whole internal surface of the mouth secretes a mucous fluid which is mixed with the food; that mucous follicles, situated in different parts of the mouth, continually pour out a considerable quantity of the same kind of fluid, and that there are in addition six large glands, termed salivary, three placed on each side, the special office of which is to prepare the saliva, which, as has been stated, flows in such abundance during mastication that according to the common estimation it amounts to upwards of eight ounces during a single meal. It can scarcely be doubted that the maceration of the crude aliment in a fluid thus abundantly and especially provided for the purpose by secretion, exerts some influence over it beyond that of merely softening it.

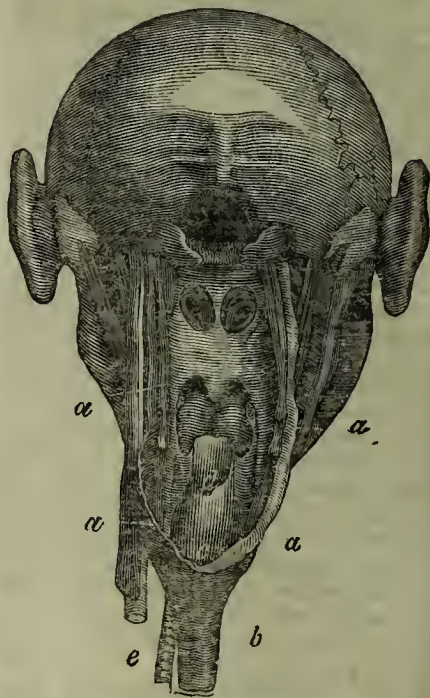
Of Deglutition.

When the food is completely comminuted, and sufficiently softened by imbibing the fluids of the mouth, it is conveyed into the stomach by the action of deglutition. Deglutition is not a mechanical, but is altogether a vital action. The food does not descend through the œsophagus by its own gravity, but is propelled by muscular contraction. Few parts of the animal structure exhibit a more beautiful specimen of mechanism than the arrangement and action of the organs that are concerned in this function. Simple and easy as it appears, it is really extremely complicated: it is produced by the contraction of a great number of muscles, and it requires the concurrence of several very important organs. Each part of the apparatus produces an independent specific effect, and the result of their combined action

is the attainment of the object in the most perfect manner.

As soon as it is sufficiently comminuted by the teeth, the aliment is collected together and moulded into a suitable form by the combined action of the muscles of the cheeks and tongue. Thus prepared, the morsel is conveyed by the action of these organs to the dorsum, or upper and back part of the tongue, and the tongue pressing with its apex against the palate as against a fulcrum, conveys it into the pharynx, a musculo-membranous bag situated in the back part of the throat (*fig. 38, a a a*). By one

Fig. 38.



Represents the back part of the head with the ears: or a posterior view of the pharynx, and other parts described; *a, a, a, a*, represent the bag of the pharynx cut open in order to allow the other organs to be seen; *b*, the continuation of the bag of the pharynx, which is seen to be contracted into the form of a tube, called the œsophagus, and which terminates in the stomach; *c*, the glottis; *d*, the epiglottis; *e*, the trachea. Other cavities are seen opening into the great bag of the pharynx; two above which represent the openings into the pharynx from the nostrils, and one below from the mouth.

set of muscles, with which it is in connection, the pharynx, the moment the tongue is ready to transmit the morsel to it, is drawn upwards in order to receive it; and by another set of muscles it is also at the same instant expanded, this simultaneous elevation and opening

of the bag being indispensable to its reception of the food. Having received the morsel, the muscles of which the pharynx is composed are stimulated to contraction by its contact. By the contraction of these muscles the morsel is compressed and propelled into the œsophagus, which latter organ is constantly kept in a moistened state by mucous fluid, which considerably facilitates the passage of the food. Numerous other openings (*fig. 38*), several of them of considerable size, and which are connected with organs that perform some of the most important functions in the economy, are situated either in the pharynx, or in its immediate neighbourhood. It was necessary to guard with special care against the entrance of the food into either of these openings, for such an event would be attended, in any case, with great inconvenience, and in some, with almost instant death. The variety, the simplicity, and yet the efficacy of the expedients which are adopted to prevent such an occurrence, cannot be contemplated without the highest admiration.

From the pharynx the food is conveyed, as we have seen, to the œsophagus (*fig. 38, b*). The superior part of the œsophagus, which is continuous with the pharynx, is, like it, at first expanded to receive the morsel, and is then excited to contraction by its contact. By this contraction it is propelled onwards; the mucus with which the entire surface of the œsophagus is lubricated facilitating its passage, while the pressure of the morsel above first of all distends that part of the œsophagus which is immediately below, and then by its presence stimulates its muscular fibres to contraction. By these alternate dilatations and contractions the morsel is at length propelled into the stomach.

On carefully observing these successive actions, it is found that the morsel passes with very different degrees of rapidity through different parts of its course. On watching the action of the organ, Boerhaave was so struck with the extreme rapidity of its motion, that he said, the food is transmitted through the pharynx by a convulsive action of its muscles. The necessity of this will be perceived, when it is remembered that the larynx, the commencement of the air-tube of the lungs, is placed before the pharynx (*fig. 38, d, c, e*); that this air-tube must necessarily be closed while the food passes over it, and that the

closure of its opening, only for a few seconds, would materially obstruct the function of respiration, one of the most indispensable functions of the animal economy. M. Magendie has shown that the progress of the food through the œsophagus is exceedingly different; that it occasionally stops at different parts of the passage; that it remains some time at each station, and is often two or three minutes in reaching the stomach. For the reason just assigned, were this delay to take place in the pharynx, it would inevitably occasion death. Deglutition, then, consists of three distinct stages; first, of the passage of the food from the mouth into the pharynx; secondly, from the pharynx into the œsophagus; and thirdly, from the œsophagus into the stomach.

Of the Arrangement of the Food in the Stomach.

We owe to Dr. Wilson Philip an interesting account of the phenomena which take place immediately after the food is received by the stomach. The alimentary mass passes first into the cardiac portion of the organ (*fig. 30, b*). It is in this part of the stomach that digestion is most actively performed. In cases of sudden death, after a full meal taken, when the person was in sound health, the coats of the stomach itself are apt to be digested: but this digestion of the organ is most commonly found in its cardiac portion. Dr. Philip states, that if a rabbit be killed soon after eating a hearty meal, the cardiac extremity will be found completely digested in almost every instance; but that, in the numerous experiments he has performed, he never saw the coats of the organ eaten through, excepting at its large end. Although, after death, the stomach must be equally subject to the action of the gastric juice as any other dead animal matter, yet it is not a little extraordinary that the gastric juice of the rabbit which, in its natural state, refuses animal food, should be capable of digesting its own stomach, so completely as to leave not a single trace of the parts on which it has acted.

The digestion of the food always takes place from the surface towards the centre of the mass: the nearer it lies to the surface of the stomach the more it is acted on, and that part of it which is in actual contact with its wall is more digested than any other portion.

The new food is never mixed with the

old: the new is always found in the centre, surrounded on all sides by the old: if the old and the new are of different kinds, the line of separation between them is so evident that the old may be completely removed without disturbing the new; and if they are of different colours, that line can often be distinctly traced through the walls of the organ before it is opened.

In proportion as the food is digested, it is gently moved along from the cardiac (*fig. 30, b*) towards the pyloric end (*fig. 30, e*). As the layer which lies next the surface of the stomach first undergoes the requisite change, and is propelled onwards by the muscular action of the organ, so the portion which lies next it succeeds in turn to be submitted to the same process. The gastric juice, at the same time, pervades in a greater, or less degree, the entire alimentary mass, so that when the central part comes into contact with the surface of the stomach, its digestion is already considerably advanced.

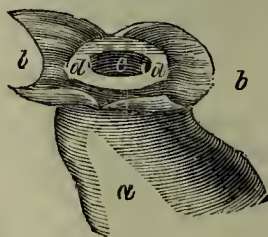
The food remains in the stomach upwards of an hour before any change in it becomes perceptible. It is commonly stated that a meal is completely digested in the human stomach in about four or five hours. If this statement be correct, the digestion in other animals is much slower. In experiments performed on dogs which had eaten as much flesh as they chose, and which were killed six hours after the meal, it was found that the stomach was still nearly full, and that the surface of the food next the wall of the stomach was acted on throughout in the manner just described. From the experiments of Dr. Philip, it appears that, in the rabbit, the central part of the mass of food in the cardiac portion of the stomach was not as much digested as that next the surface of the organ, until the animal had fasted sixteen or eighteen hours. And Sir Everard Home states that the stomach of this animal is never completely empty, but that when it dies after fasting, however long continued, it is always found to contain a considerable quantity of food.

It has been stated that, as the aliment is digested, it is gradually accumulated at the pyloric extremity of the stomach. This portion of the food has experienced the most complete digestion which it is capable of undergoing in this organ, and is termed chyme. Chyme is a pul-
taceous and almost fluid substance, of

a greyish colour, of a sharp odour, and of an acid taste, reddening paper coloured with turnsole. It is commonly said to be perfectly homogeneous in its nature; and that, whatever be the species of the food, the resulting mass is uniformly the same, never exhibiting any of the sensible properties of the crude alimentary matter. But this statement is not correct: for we learn by actual experiment that chyme produced from vegetable differs in colour, in consistence, and in some other sensible properties from that procured from animal substance.

When thus completely formed in the stomach, the chyme is gradually propelled by the alternate contraction and relaxation of the muscular fibres of the organ towards its pyloric extremity (*fig. 30, e*). Here it accumulates in a certain quantity before it is permitted to pass through the pylorus: which, as has been stated, consists of a ring of muscular fibres, of the structure and arrangement of which it is impossible to convey an accurate idea by any plate; but the position of which is represented by the white ring, marked *d, d*, in *fig. 39*; while its opening, through which the chyme passes, is pointed out by the

Fig. 39.



a, pyloric extremity of the stomach; *b, b*, section of the beginning of the duodenum; *d, d*, the ring of muscular fibres constituting the pylorus; *c*, the opening of the pylorus, through which the chyme passes from the stomach to the duodenum.

Fig. 40.



Represents the pylorus in the natural state, in which it is more contracted than when distended and dried.

letter *c*. It would appear that the accumulation of the chyme at this extremity of the stomach, never exceeds four ounces at any one time. M. Magendie states that in the numerous experiments in which he has had an opportunity of observing it, he has uniformly remarked that when it amounts to about two or three ounces, it is admitted through the opening of the pylorus into the duodenum (*fig. 39, b b*). Nothing in the animal economy is more curious and wonderful than the action of that class of organs of which the pylorus affords a remarkable example. If a portion of undigested food present itself at this door of the stomach, it is not only not permitted to pass, but the door is closed against it with additional firmness: or, in other words, the muscular fibres of the pylorus, instead of relaxing, contract with more than ordinary force. In certain cases, where the digestion is morbidly slow, or when very indigestible food has been taken, the mass is carried to the pylorus before it has been duly acted on by the gastric juice: then, instead of inducing the pylorus to relax in order to allow of its transmission to the duodenum, it causes it to contract with so much violence as to produce pain, while the food thus retained in the stomach longer than natural disorders the organ; and if the digestion cannot ultimately be performed, that disorder goes on increasing until vomiting is excited, by which means the load that oppressed it is expelled. The pylorus is a guardian placed between the first and the second stomach, in order to prevent any substance from passing from the former until it is in a condition to be acted upon by the latter: and so faithfully does this guardian perform its office that it will often, as we have seen, force the stomach to reject the offending matter by vomiting rather than allow it to pass in an unfit state: whereas, when chyme duly prepared presents itself, it readily opens a passage for it into the duodenum. This eminently vital property of the muscular fibre, of most essential and varied use in the economy, by which it is obedient only to particular stimuli, will be further spoken of hereafter.

Of the Formation of Chyle.

In the duodenum the chyme undergoes a further change. After it has been a short time in this organ it is observed to separate into two parts, into

a white fluid, which is detached from the common mass, and which constitutes the proper nutritive substance: this is termed chyle: and into a residual matter which is not nutritive, but which is ultimately converted into fæces and rejected from the system. We are as ignorant of the mode by which chyme is converted into chyle, as of that by which the crude alimentary matter is changed into chyme: but as the agent by which the former is produced may be considered as ascertained, so that by which the latter is effected may be stated to be known with a high degree of probability. It is observed that the chyme, soon after it enters the duodenum, is mixed with two specific secretions, that of the pancreas (*fig. 35, C*), which is termed the pancreatic juice, and that of the liver (*fig. 32, A A*), which is called the bile. In living animals the bile is seen to exude, at intervals, from the excretory duct of the liver termed the *ductus communis choledochus* (*fig. 32, F*). A drop appears at the orifice of the canal, and diffuses itself over the neighbouring surface about twice in a minute. It is remarked that the pancreatic secretion is admitted to the intestine through the pancreatic duct (*fig. 32, G*) still more slowly. The chyme is observed to be accumulated in the greatest quantity about the orifice of the *ductus communis choledochus*. The moment the bile is mixed with it, a striking change takes place in the entire mass: it loses its own sensible properties, and acquires those of the bile, especially its colour and bitterness. In a short space of time a spontaneous change is observed to take place in the compound: it separates into a thick, whitish, cream-like fluid, and into a yellow pulp: the white fluid is the chyle; the yellow pulp is the excrementitious portion. Both together are now slowly carried along the small intestines (*fig. 32, K K*). The chyle thus separated from the chyme, is found already to possess the most remarkable property of the circulating blood, namely, that of coagulation. It is observed to adhere with some tenacity to the internal or mucous coat of the intestine; for if this portion of the canal be examined in an animal killed after having recently taken food, this matter will be found in a state of coagulation adhering with considerable firmness to the mucous coat. This adhesion of the chyle to the surface of its containing tube, does not appear to arise from any

adhesive property in the chyle itself, but is supposed to be rather the effect of a species of attraction exerted by the mucous coat for this peculiar matter : to be a vital action referrible to a class of vital actions highly curious in their nature, of which the animal economy affords numerous examples. It was necessary that the nutrient matter should be brought into a certain degree of contact with the mucous surface of the intestine, and should be held in contact with it for a certain length of time, in order that the lacteal vessels might have the means of absorbing it: the mucous membrane of the intestine is therefore endowed with the power of attracting this matter to itself: thus exhibiting a beautiful example of that peculiar relation, or, as it is sometimes termed, consent between containing and contained parts which is so characteristic of life. The progress of the chyle through this part of the canal, is likewise rendered slower by the folds of the mucous membrane, termed the *valvulæ conniventes* (fig. 34). As it passes along the tube it gradually disappears, becoming smaller and smaller in quantity, until at length it is nearly lost at the point where the small intestines terminate in the large (fig. 33, E). The yellow pulpy substance forming the excrementitious part of the aliment is transmitted from the ileum, the last of the small intestines to the cæcum, the first of the large (fig. 33, E); whence it passes through the whole tract of the latter, and is finally conveyed out of the body in the form of fæces.

The chyle nearly approximates to the nature of the blood. Like it, when removed from the body, as has just been stated, it spontaneously coagulates; that is, it separates into a dense whitish mass termed the coagulum, and into a transparent colourless fluid. The basis of the coagulum is found to be a substance closely resembling the fibrine of the blood, and the fluid part to be very similar to its serum: it exhibits the same chemical properties as the corresponding parts of the blood, and it also resembles this fluid in the nature of its salts: but all these circumstances will be better understood after the blood has been described. It has been already stated that when the chyle is examined with the microscope it is found to consist of innumerable globules; that these

diligence by Dr. Edwards, who informs us that they are exactly of the same magnitude, and possess precisely the same physical properties as the central globule of the blood when divested of its external colouring envelop. This distinguished physiologist likewise maintains that both the globule of the chyle and the central globule of the blood exhibit precisely the same physical properties as the globules that compose the primitive tissues of the body; and that thus, as soon as the fluid which is destined to nourish the body is formed, the organic molecules of which the body itself consists are discoverable in it. Later microscopical observations, however, place in considerable doubt the accuracy of those which have preceded.

Of the Digestion of Fluids.

Fluid substances obviously require to be subjected to none of the preparatory processes which are indispensable to the digestion of solid aliment: they need no mastication and no admixture with the liquids of the mouth. Their deglutition is more easy and rapid on account of their greater divisibility. The series of changes they undergo in the stomach, is by no means well understood. It is ascertained that they remain a much shorter time in the stomach than solid aliment. If the stomach of an animal be examined very shortly after it has drunk copiously, it is found completely empty of fluid. Until lately, it was supposed that fluids like solids are transmitted from the stomach to the duodenum through the opening of the pylorus, and their rapid disappearance was accounted for from their finding a ready passage through the pylorus, on account of their easy divisibility. But M. Magendie has shown that if a ligature be placed around the pylorus, so as to prevent the possibility of their exit through that aperture, they disappear from the stomach with almost equal rapidity. Recently, professors Tiedemann and Gmelin have investigated this subject with great care, and they state in the most positive manner, that they have ascertained from numerous experiments, of which it is impossible to give any account in the present place, that the fluids of the stomach are rapidly taken up by the absorbents of the organ; that they are immediately conveyed by these vessels to the liver, and that they circulate directly through that viscus. The object of this curious

disposition is at present wholly unknown, and the fact itself cannot be received without further confirmation.

Of the Theories of Digestion.

The principal theories which have been invented to connect and explain the preceding phenomena are those of concoction, putrefaction, trituration, chemical solution, vital energy, and nervous influence.

The oldest hypothesis of digestion on record, is that of concoction, which was maintained by Hippocrates, and descended down through Galen to comparatively modern times. But concoction is only another word for digestion; and to say that the function of digestion is performed by the process of concoction is not to propose a theory, but merely to employ another word to express the process itself.

That digestion is not performed by a process analogous to that of putrefaction is proved by the facts that the first effects of the application of the gastric juice to the alimentary mass is to resist putrefaction, and to suspend the process even after it has actually commenced.

The mechanical physiologists endeavoured to account for all the phenomena of digestion by trituration. Calculations were made, apparently with mathematical accuracy, to ascertain the force that would be required for the performance of the function in this mode; and accordingly Pitcairn estimates that the force of the muscular fibres of the stomach is equal to 12.951 pounds. The facts which refute this hypothesis are already before the reader: namely, first that the stomach of most animals is entirely membranous, and cannot possibly exert the requisite power; and secondly, that digestion is performed under circumstances in which trituration cannot operate, as is proved by the experiments of Spallanzani, Stephens, and others, immediately to be detailed.

The theory of chemical solution is directly favoured by all the experiments that disprove the former hypothesis. The evidence that the stomach secretes a peculiar fluid, which acts chemically upon the aliment, and that nothing further is necessary to produce these actions, than to bring the two substances into contact, may be said to be complete. Among the numerous experiments which have been performed to establish this point, the most curious and important are the following.

Spallanzani inclosed different alimentary substances in metallic balls perforated with holes, and in pieces of porous cloth. These were introduced into the stomach, and after having remained there for a certain time were withdrawn: on their removal, it was found that the matters inclosed were more or less dissolved, while the containing substances, whether metal or cloth, were not acted upon in the slightest degree. Since this effect could not possibly be produced by mechanical means, there seems no other resource, but to suppose that it was accomplished by chemical agency.

By vomiting, mechanically excited, the same experimentalist threw up from his own stomach a tube perforated with holes, and containing beef which he had swallowed four hours before. The flesh was thoroughly soaked with the fluid of the stomach: its surface was soft and gelatinous: it had wasted from fifty-three to thirty-eight grains.

1. With a view of prosecuting these researches, Dr. Stephens took advantage of a man who had been in the habit of swallowing stones, and afterwards of rejecting them from the stomach. This experimentalist caused the man to swallow hollow metallic spheres, perforated with numerous orifices, and filled with different kinds of alimentary matter. By numerous experiments, it was established that when a hollow silver sphere containing raw or cooked flesh or vegetables, and perforated with holes that would admit a crow quill, was swallowed, it was rejected *per anum*, in about forty hours, and was always perfectly empty.

2. That the gastric juice acts chemically upon the food is proved by the fact that alimentary substances in the progress of digestion present precisely the appearances which they would exhibit were they exposed to the influence of chemical agents. It is truly stated by M. Magendie, that the surface of food undergoing the process of digestion consists of a soft layer which is easily detached from the undigested part, and which has every appearance of having been acted on by a re-agent capable of dissolving it, and that the white of a hard-boiled egg, for example, appears just as if it had been plunged in vinegar, or in a solution of potash.

3. The effect produced by the gastric juice on the substances exposed to it bears no proportion whatever to their mechanical texture, or to their other physical properties. While it acts upon

the densest membrane; while it speedily dissolves bone itself, it produces not the slightest effect upon many substances of the most delicate texture; the skins of fruit, for example, and even the finest fibres of flax and cotton are not in the smallest degree affected by it. This selection of substances exactly resembles the operation of chemical affinity, and is decidedly contrary to what would be the effect of mechanical agency.

4. The gastric juice produces, on certain substances, effects which unquestionably are of a chemical nature. Thus it occasions the coagulation of albuminous fluids, and prevents putrefaction. An infusion of the proper stomach of the calf, termed rennet, is commonly employed for the coagulation of milk, a small quantity of which converts the albuminous portion of milk into the state of curd. The antiseptic power of the gastric juice was abundantly established by the experiments of Spallanzani, who observed, that in carnivorous animals, which frequently take their food in a putrid state, the first operation of the stomach was to remove this foetor. It was also found that if the gastric juice be added to substances out of the body, it resists their putrefaction, and even suspends the process when it has commenced.

But wonderful and irresistible as the action of the gastric juice is proved to be, it is destitute of any sensible properties upon which its power can depend, or with which its agency can be connected. According to every test which it is in our power to apply to it, it appears to be exceedingly analogous to saliva, or to the ordinary secretions of the mucous membranes,—fluids which, so far from indicating any active properties, are remarkable for their blandness. This apparent inertness has suggested doubts whether it really possess the active agency which is attributed to it, and has led to the institution of experiments to ascertain whether it is capable of producing effects out of the body analogous to those which it accomplishes within the stomach. In order to learn whether chyme can be formed by the gastric juice out of the stomach, Spallanzani procured this fluid from the stomachs of various animals; and on mixing it with different alimentary substances, it was found that it actually does exert an influence very similar to that which is supposed to take

place within the stomach. Some of this fluid was put into a glass tube with boiled beef that had been masticated; the tube was then hermetically sealed and exposed near the fire to a considerable heat; by the side of this tube was placed another, containing the same quantity of flesh immersed in water. In twelve hours the flesh in the tube containing the gastric juice began to lose its fibrous structure; in thirty-five hours it had entirely lost its consistence; it appeared, as far as the eye could judge of it, to be reduced to a pulaceous mass, and no further change was produced in it by the gastric fluid during the two following days. On the other hand, the flesh that had been immersed in water was putrid in sixteen hours. Although it is impossible to imitate out of the stomach several very important circumstances which occur in the natural process, yet this experiment appears to have accomplished a near approach to chymification; and upon the whole, what has been stated, may be said to present a chain of clear and satisfactory evidence leading to the general conclusion that the food in the stomach is converted into chyme by the fluid secreted from its surface, and that this change is effected by a proper chemical action.

Dr. Prout has recently discovered, that during the process of chymification, muriatic acid is always present, a fact confirmed by the testimony of professors Tiedemann and Gmelin, who state that in all their researches they uniformly detected the presence of an acid. Occasionally heat, and not unfrequently gas, are also evolved; but whether these products form a necessary part of the process when exercised in a perfectly healthy manner, or whether and how far they arise from a morbid condition of the function, is not ascertained.

Some physiologists are of opinion that it is possible to advance a step further, and to determine the particular kind of chemical action by which the gastric juice produces the requisite changes in the food. They think the facts observed warrant the conclusion that it acts as a specific ferment. In chemical solution, two bodies act upon each other and produce a third substance possessed of new properties; in fermentation, the elementary principles of bodies are disengaged, and enter into new combinations. Now, since there is reason to believe that every compound substance must be de-

composed in order to fit it for nutrition, it is argued that this very reason seems to justify the conclusion, that the process of digestion does not consist in their chemical solution, but in a specific fermentation. And it is further stated in favour of this view, that there are several specific fermentations with which we are acquainted; for example, the vinous, the acetous, the panary; and that there are probably others which are at present unknown, of which what may be termed the chylous may be one. It must be admitted, however, that while there is much probability in this supposition, and while the evidence can scarcely be resisted that digestion is performed by a chemical action of some kind, yet that we are at present wholly ignorant of the particular nature of that action.

From the difficulty of accounting in a satisfactory manner for this process either upon mechanical or chemical principles, some physiologists have ascribed it to the agency of what they have termed the vital principle. The internal surface of the stomach, they say, is endowed with a specific property which belongs to it as a living substance, and which enables it to digest the food. When the meaning of this language is strictly analyzed, it will be found to amount to no more than that the process of digestion is peculiar to the condition of life, and that it is never observed to take place in any other state. But this, like the ancient doctrine of concoction, is merely the adoption of a peculiar mode of expressing the fact, and not a reference of the fact to an efficient cause.

Lately many observations and experiments have been adduced to show that digestion is essentially a nervous function, depending upon the direct agency of the nervous system. Thus it is ascertained by direct experiment that this process is suspended by dividing the eighth pair of nerves. Dr. Philip states that if an animal be allowed to live a considerable time after a part of this nerve is removed, the food remains unchanged in the stomach, and is nearly in the same state in all parts of the organ; that this effect is quite uniform, and that in all his experiments he has never seen it otherwise. This fact, which has been conceived to be decisive in favour of the nervous hypothesis, proves only that the influence of the eighth pair of nerves is essential to the secretion of the gastric

juice, and therefore does not bear upon the subject of digestion, but merely upon that of secretion. And Dr. Holland has endeavoured to prove from Dr. Philip's own experiments, that the division of the eighth pair arrests the process of digestion, by interrupting the respiration, and consequently the circulation, and that it is thus through the lungs and heart that the secretion of the gastric juice is prevented. And it is remarkable, that if Dr. Philip's experiments be examined, it will be seen that the respiration was simultaneously affected with digestion.

Having thus considered the general facts to which the most eminent cultivators of this science have conceived that the particular fact of digestion may be referred, we shall conclude this subject by saying a few words relative to the different substances, on which the digestive organs are capable of acting, and by adverting to the true nature of the sensations of hunger and thirst.

Of the Food of Plants and Animals.

The proper food of plants is water and air: both are indispensable to the subsistence of this class of organized beings. Some plants indeed appear to subsist on air, and others on water only: but the æriel epidendrum, without doubt, derives its moisture from the water suspended in the atmosphere. The quantity of air naturally mixed with water is found to afford an adequate supply of this fluid to some aquatic plants, but it is proved by direct experiment, that if totally excluded from air, plants uniformly die. Soils are not the food of plants: soils may be considered as the fixed abode of plants, and as the medium through which they receive a great portion of their nourishment. Soils are composed of earths, silica, lime, alumina, magnesia, the oxides of iron and manganese; they contain also vegetable and animal substances in a state of decomposition, together with saline, acid, and alkaline combinations. The fertility of a soil depends essentially upon its capacity to retain water: to hold it much in the condition in which it is retained in the sponge—that is, not in a state of aggregation, but of minute division; so that every part may be moist, but no part wet. Earths, beside affording the requisite degree of adhesiveness and looseness to retain and distribute moisture in this manner, fix the plant in the ground, and support it

therein. Whatever other useful purposes the admixture of mineral substances in the soil may accomplish in the economy of the plant, it is probable that they act as stimulants upon the capillary rootlets, and that they may be to the plants what condiments are to the animal.

Plants are interposed between the inert soil and the living being, between inorganic and organic matter; and appear to be the great laboratories in which are formed, out of inorganic materials, those elementary organic particles by the assimilation of which the higher classes of living beings exist. Consisting, for the most part, of organic particles, which are capable of being assimilated in the digestive organs of animals, vegetables in general are adequate to the support of animal life. Vast tribes of animals, however, subsist entirely on animal matter; and there are correlative tribes, the main purpose of whose existence seems to be to convert vegetable into animal matter, in order to afford the materials of support to those endowed with higher organization. As the vegetable prepares organic particles from inorganic matter, so these animals appear to convert the particles thus organized into animal substance, that the process of assimilation in the higher animals may be shortened. Large tribes of animals, however, high in the scale of organization, live entirely upon vegetable matter; others subsist solely upon animal substance; while others are supported in the most perfect health and vigour by a combination of both. We have seen that the digestive organs of animals which live on vegetable matter differ considerably from the digestive organs of those which are supported by animal substance. The successive changes that are necessary to the complete digestion of vegetable matter are more numerous; and hence in all herbivorous animals the alimentary canal, as we have seen, is much larger and more complicated than in those which subsist on animal food.

We know that in the digestive organs of an animal, the vegetable is changed into animal matter, and that the vegetable has the power of reconverting animal into vegetable substance: hence the utility of manure in promoting the process of vegetation; some kinds of manure consisting almost entirely of animal matter in a state of decomposition. We have seen that both vegetable

and animal matter consists of the same ultimate elements differently arranged, and combined in different proportions, and that every article of food must undergo a complete decomposition before it is fitted for the purpose of nutrition. We may conceive, then, that in the process of vegetable digestion, the ultimate elements are enabled to enter into those peculiar combinations which constitute vegetable matter; and that in the process of animal digestion they are enabled to enter into those which constitute animal matter; these combinations depend on the attractions which different species of matter exert: these attractions differ according to circumstances. In the stomach of an animal, the elements of alimentary substances being disengaged, we must suppose that circumstances are always so arranged as to secure by the affinities of these substances for each other, just such a recombination of them as is necessary to constitute chyme. This, it is true, amounts to nothing more than an expression of the fact, and affords no explanation of this most curious and mysterious process; but still this mode of expressing it may enable us to form a just conception of the nature of the fact itself.

It has been stated that both vegetable and animal matter consists of the same ultimate elements, namely, oxygen, hydrogen, carbon and azote; and that, of these, vegetables in general contain three only, being for the most part destitute of azote or nitrogen, or containing it only in small quantity. They have also less hydrogen; while on the other hand they contain a much larger proportion of carbon.

It has been further stated that the ultimate elements of vegetable and animal substances combine together in different proportions, and thus form different products; and that from the most simple of such combinations, certain substances result, which, on account of the simplicity of their composition, are called Primary Compounds, or Proximate Principles. The most important primary compounds or proximate principles of vegetable origin are, gluten, farina, mucilage, oil, and sugar. These substances possess very different nutritive properties. Gluten is by far the most nutritious of them all; its elements most nearly resemble those of animal matter: it contains nitrogen in considerable quantity—the element which has

been stated to be absent from almost all the vegetable products. Of all vegetable substances, gluten is found in the greatest proportion in wheat.

Next to gluten, in the property of affording nourishment, is farina. This, likewise, is found most copiously in wheat. It also forms a considerable portion of the nutritive parts of various kinds of pulse and of tubers.

Leaves, stalks, seed-vessels, and the green parts of plants, afford the principal nourishment to many species of animals. The nutritive principle contained in these articles of food resides chiefly in mucilage, though to this is commonly united a portion of saccharine matter which contributes materially to its nutritive power. Most fruits contain a basis of mucilage, or farina, which is combined either with sugar or with oil. Sugar is among the most highly nutritive of all the vegetable products, and oil seems capable of being converted almost wholly into nutrient matter.

The most important of the proximate principles of animal origin which are employed as articles of diet, are fibrin, albumen, jelly, oil, osmazome, or the extractive matter of the muscular fibre which seems to give the specific flavour to the flesh of different animals: it is probable that it consists only of fibrin slightly altered by heat. There are some others, but they are of little consequence.

Articles of diet may be contemplated in two points of view, as nutritive, and as digestible. They are nutritive in proportion to their capacity of affording the elements of chyme: they are digestible in proportion to the facility with which they undergo the necessary changes in the stomach. There is an essential difference between these two properties, nor do they by any means bear an exact proportion to each other. Many substances which contain the elements of chyme in the greatest abundance are digested with difficulty; and it is remarkable that this difficulty is sometimes exceedingly lessened by mixing with them other substances that are less nutritive.

Animals, when in a natural state, adhere with remarkable uniformity to the same kind of food. There are many carnivorous animals which feed only on a certain kind of flesh; some upon the flesh of quadrupeds; others, again upon that of birds, and others upon that of insects. Among herbivorous animals, some sub-

sist only on certain plants; others only on certain parts of particular plants, as the seed, the fruit, the leaves, and so on, while entire tribes of insects appear to be exclusively attached to some one species of vegetable matter. There is generally a manifest connection between the substances on which these animals feed, and the structure of the teeth, indicating that the selection is not the effect of accident, but depends upon the original conformation of the body. We have seen that the teeth of different animals are adapted, some for seizing and biting; others for tearing and lacerating; others for cropping the more succulent and delicate parts of plants, and others for masticating those that are firm and dense in their texture. The beaks of birds are infinitely diversified in their form and structure, some are long and pointed, others are broad and flat; others are hooked or curved. On carefully examining these diversities in their structure, it is found that each is adapted for receiving only certain kinds of food. And in all cases, the nature of the stomach, whether membranous, muscular, or ruminant; whether simple, consisting of one cavity only, or compound, divided into several distinct chambers, precisely corresponds to that of the teeth, and to the other organs and habits of the individual.

From whichever of these two great sources of nourishment the food of animals is derived in their natural state, nature has allowed to most of them a wide range in the power of abstracting it. Even those which most obviously and decidedly prefer one particular species of food, may gradually be brought to subsist well on the opposite; and man whose digestive organs evidently place him between those of carnivorous and herbivorous animals, has more power than any other of accommodating himself to widely different kinds of nourishment. Many observations and experiments show, that in him, at least, a mixture of various diet is not only consistent with health and vigour, but is highly conducive to both.

This point is abundantly illustrated by Dr. Stark of Vienna, who ultimately fell a victim to the zeal with which he prosecuted his researches, and who made himself the subject of a highly curious series of experiments upon the relative effect of various simple substances when used exclusively as articles of food for a long space of time. The

result showed that the body is invariably brought into a state of extreme debility by such a course of diet, and that there is not a single article of food, not even the most nutritious, that is capable of sustaining the vigour of the body, or even of maintaining life itself for any considerable period. By selecting one after another, single and simple articles of food, and by confining himself exclusively to one, this experimentalist so irretrievably ruined his health, as to bring on premature death.

M. Magendie has recently resumed these researches, and afforded additional evidence of the justness of the conclusion suggested by the experiments of Dr. Stark.

A dog, fed exclusively upon white sugar and water, appeared, for seven or eight days, to thrive well upon these substances: he was lively, and ate and drink with avidity: towards the second week, however, he began to lose his flesh, though his appetite continued good. In the third week he lost his liveliness and appetite. An ulcer formed in the middle of each cornea, which perforated it, and the humor of the eye escaped: the animal became more and more feeble, and died on the thirty-second day of the experiment. Results nearly similar ensued with dogs fed upon olive oil and distilled water; but no ulceration of the cornea took place, and analogous effects were observed in dogs fed upon gum and upon butter.

A dog, fed with white bread, made from pure wheat with water, died at the expiration of fifty days. Another, fed exclusively on military biscuits, suffered no alteration in its health.

Rabbits and guinea-pigs fed upon one substance only, as corn, hay, barley, cabbage, carrots, and so on, die, with all the marks of inanition, generally in the first fortnight, and sometimes sooner.

An ass, fed upon boiled rice, died in fifteen days, having latterly refused its nourishment.

Dogs, fed exclusively with cheese or with hard eggs, are found to live a considerable period; but become feeble, meagre, and lose their hair.

When a certain degree of emaciation has been produced by feeding an animal for some time upon one substance, as, for instance, upon white bread during forty days, the animal will eat with avidity different kinds of food offered to it at that period, but it does not regain its strength; it continues to waste, and dies

about the same time at which its death would have happened, had the exclusive diet been continued; the digestive organs are irreparably injured, and the due stimulus though applied to them cannot now restore them.

M. Magendie adduces the preceding experiments to prove that a proportion of nitrogen is necessary for the support of animals. He conceives that the reason why the animals on which his experiments were performed, could not live for any length of time upon pure sugar, is because these substances are destitute of nitrogen. Dr. Bostock justly observes, that these experiments prove no more than that the stomach is not capable of digesting these substances without some addition. Dr. Stark's experiments furnish us with many examples of the indigestible nature of a diet composed of a single article, which was easily digested when mixed with other substances. In order to render M. Magendie's experiments decisive of the point for which he adduces them, it would be necessary to employ a diet, which should be composed of a mixture of substances—all of them without nitrogen—as farina, mucilage, or gum, mixed with sugar or oil.

These experiments abundantly prove the necessity of varying the articles of food. This necessity probably arises from the following cause, which the reader will understand better hereafter. The stomach, like other organs, can be excited to the due performance of its functions only by supplying it with an appropriate stimulus. By a long and uninterrupted continuance of one and the same alimentary substance, that substance probably loses its stimulating power, and thus, though it abound with nutritive properties, the stomach is incapable of acting upon it.

Sir Astley Cooper has made various experiments upon the digestibility of several substances which are commonly employed as articles of diet. He gave, for example, to dogs a determinate quantity of pork, mutton, veal, and beef, preserving a register of the figure of the pieces swallowed, and of the order of their introduction into the stomach. Opening the animals at the end of a certain period, and collecting with care what remained in the stomach, he ascertained that pork was the substance most rapidly digested; then followed mutton, then veal, and lastly, beef, which seemed to him the least digestible

of all. In some cases the pork and mutton had entirely disappeared, when the beef still remained untouched.

By other experiments he found that fish and cheese are also very digestible substances. Potatoe is somewhat less so; the skin which covers it passes into the duodenum without change.

He tried some experiments with the same substances prepared in different ways. He found that boiled veal is two-thirds more digestible than the same substance roasted. Divers other substances were likewise submitted to similar experiments. Thus he found that muscular flesh was sooner digested than skin; skin a little sooner than cartilage; cartilage sooner than tendon, and tendon than bone.

Some of the results of these experiments, but not all of them, accord with commonly received dietetic principles, and with the experience of dyspeptic persons. The human stomach, when weak and deranged, is usually observed to digest the lean part of pork and boiled mutton, more readily and with less inconvenience than any other animal substances.

There are several substances which, though they contain in themselves no nutritive property, yet exert a considerable influence in promoting digestion: these are commonly termed condiments. Condiments consist, for the most part, either of salts or spices; they probably act on the principle already stated, affording a stimulus to the stomach by which it is excited to a more energetic performance of its functions. Possibly, also, they may exert some corrective influence over the various species of aliment during the process of digestion. Thus the tendency of vegetable substances to the acetous fermentation may be checked by aromatics and spices, and the tendency of animal matter to pass into a putrid state may be prevented by salts and acids.

Somewhat analogous to condiments in their effects upon the stomach, is the action of certain medicines, which, though they afford no nutriment, yet serve to put the stomach into a state which adapts it for the digestion of the aliment. There is this essential difference between articles of diet and condiments and medicines. No substance, as has been stated, can contribute to nutrition, until it is resolved into its ultimate elements: condiments and medicines, on the contrary, act in their

entire state, and cease to produce their appropriate effects the moment they are decomposed. The most virulent poisons, whether derived from the vegetable, the animal, or the mineral kingdoms, become perfectly inert when resolved into their elementary constituents. Dr. Fordyce observes, that certain insects live entirely upon cantharides, while their fluids are perfectly mild; and that even the poison of the rattle-snake is perfectly innocent when taken into the stomach.

An adult person, in sound health, taking moderate exercise, appears to require two hearty meals in the day: in states of disease a third repast is necessary; for the stomach, when weakened, digests food better if it be given in small quantity. In these cases, the adoption of the plan suggested by Mr. Abernethy is found in practice to be attended with the most beneficial effect—that of dividing the food to be taken in the day (suppose twelve ounces) into three equal portions, and taking each meal with strict regularity after an interval of six hours. It is astonishing how rapidly and completely the energy of the stomach sometimes returns under this treatment, in cases in which its function has been merely deranged, and to how great an extent suffering is relieved even when the total and permanent removal of it is hopeless.

During infancy and childhood, when an abundant supply of materials is required to build up the enlarging frame, the appetite is proportionably keen; the stomach appears to digest simple food more rapidly, and craves more frequent meals. Protracted exertion, with a scanty supply of nourishment, if not continued for so long a period as to destroy the tone of the stomach, produces in adults a voracious digestion resembling that of childhood. The digestive organs are fitted by such abstinence for the active service required of them in providing materials for the restoration of the frame.

Mr. Hunter was in the habit of quoting, in illustration of this point, the following extract from Admiral Byron's narrative. After describing the privations which he had suffered when shipwrecked on the coast of South America, the admiral incidentally mentions their subsequent effect upon his appetite. "The governor," says he, "ordered a table to be spread for us with cold ham and fowls, which only we three sat down to,

and in a short time dispatched more than ten men with common appetites would have done. It is amazing that our eating to that excess we had done from the time we first came among these kind Indians, had not killed us, as we were never satisfied, and used to take all opportunities, for some months after, of filling our pockets when we were not seen, that we might get up two or three times in the night to cram ourselves."

Nothing promotes appetite more than moderate exercise in fresh air, and nothing is more adverse to it than sedentary occupations in close towns and ill-ventilated apartments; yet to such situations great numbers of the human race are doomed, and the effects are but too visible in their pallid countenances and their feeble frames; and but too acutely felt in the misery that results from the languid manner in which all the vital functions are performed. As long as society is constituted as it is at present, the great majority of the people appear to possess no means of escape from these terrible evils; nor are the distinguished few, whose success in the great struggle of life is commonly conceived to be the most complete and splendid, exempted from them. They may acquire wealth, and science, and fame, but the acquisition must be admitted to be dear, when the consequence is, as it too often is, the ruin of those physical organs, without the health and vigour of which there cannot be a moment's ease, nor the slightest degree of enjoyment.

Of Hunger.

Before concluding the subject of digestion, it may be proper to notice two affections of the stomach which are intimately connected with the process. The first of these is hunger. Hunger is a peculiar sensation which is universally referred to the stomach: the only cause that produces it, is a deficiency of food: it is commonly classed among the impressions which belong to the sense of touch, but it bears no kind of analogy to impressions belonging to this or to any other sense: it is altogether peculiar and specific.

Conceiving that its physical cause must be either mechanical or chemical, some physiologists belonging to the mechanical school have ascribed it to the friction of the sides of the stomach when it becomes empty. But from the

description which has been given of the structure and position of the organ, it must be obvious that it is quite impossible for its different internal surfaces ever to come into forcible contact with each other. Besides, as has been just stated, the feeling of hunger is of a specific nature, and is totally different from the mere sense of resistance.

By the chemical physiologists, the sensation of hunger is accounted for by the action of the gastric juice upon the internal surface of the stomach, which they suppose to have a tendency to corrode it. The solvent power of the gastric juice, however, as we have seen, is confined to dead animal matter; and there is no reason whatever to suppose that it possesses any corrosive properties similar to those of a chemical acid.

It is probable that hunger is a peculiar perception depending on a specific impression conveyed to the brain by the nerves of the stomach, in the same manner as the impressions connected with the organs of sense depend upon peculiar impressions communicated to the brain by their appropriate nerves. It is also probable that the impression is produced upon the nerves of the stomach, through the intervention of the gastric juice, in a manner perfectly analogous to the action of light upon the retina. As light is the appropriate stimulus to the nerve of the organ of vision, so the gastric juice appears to be the appropriate stimulus to the sentient nerves of the stomach.

The sensation of hunger is in itself painful, and therefore may, at first view, appear to afford an exception to a general law of the animal economy, namely, that there is no arrangement for the purpose of producing pain, but on the contrary, that the natural and due exercise of all the organs is productive of pleasure. It has been much and justly insisted on, that of no contrivance in the body can it be truly said—"this is to inflame; this is to irritate." And yet the action of the gastric juice upon the sentient nerves of the stomach is painful, often highly painful; and it may be argued that the production of pain is the special object aimed at. A little consideration, however, is sufficient to show that this case falls under a very general law of sensation, namely, that pain arises, not when the stimulus which produces it is moderate, but only when it is in excess. Light admitted to the retina in moderate quantity is not pain-

ful but grateful: in great intensity, it is intolerable. In like manner the sensation of hunger, when moderate, is not painful but grateful: it is only when, from protracted fasting, the gastric juice accumulates and produces an excessive stimulus, that it becomes painful. And the object of this pain, or the use it serves in the economy, is too obvious to require notice. It is the monitor by which we are warned of the necessity of supplying the system with those materials which are requisite to renovate and maintain the integrity of the body. And it is a monitor whose voice it is not possible to disregard, for its importunity increases with the increasing demand occasioned by the wants of the system. It belongs to the class of affections termed appetites, and of which it has been justly observed, that they are distinguished by three remarkable characters. They are compounded both of a physical and a mental operation: they are connected with some evident useful purpose in the economy, and they are brought about by the intervention of the nervous system.

Of Thirst.

Thirst is a peculiar and uneasy sensation, which is commonly referred to the tongue and fauces, and which is conceived to depend upon a deficiency of the mucous secretions of those organs. There are circumstances which seem to show that the seat of this affection is more extensive. In a remarkable case published by Dr. Gairdner, of Edinburgh, it was found impossible to allay the thirst, merely by supplying the mouth, tongue, and fauces with fluid. A man had cut through the œsophagus: an insatiable thirst arose: several buckets-full of water were swallowed daily, and discharged through the wound, without allaying the affection: on injecting water mixed with a little spirit into the stomach, the thirst was quenched.

The sensation of thirst, like that of hunger, is a peculiar and specific perception; also, like it, depending on a specific impression conveyed to the brain by an appropriate set of nerves, and moreover perfectly analogous in the use it serves in the economy. The supply of fluids is, if possible, still more necessary than the supply of solids, to repair the waste of the system. Probably, on this account the demand is rendered more urgent by the greater intensity of the sensation, and by the acute pain

occasioned by any considerable postponement in the gratification of the appetite.

Of the Blood.

We have seen that when the aliment is converted into chyme in the stomach, and the chyme is changed into chyle in the duodenum, the latter fluid is conveyed along the track of the small intestines, where it gradually disappears. It disappears, because it is absorbed by the mouths of innumerable vessels termed lacteals, hereafter to be described, which convey it by a route, which it will be more convenient to detail in another place, into the blood. Thus, the chyle is the fluid by which the blood is replenished; and in man, living in society, and taking his meals according to the general usage of civilized life, it is seldom that the formation of chyle is not going on in the economy, and that the vessels which transmit it from the intestines to the blood are empty or idle.

It has been stated that the chyle differs but little from the blood, excepting in colour, and that it exhibits some of the most peculiar and distinctive properties of this fluid. Other processes, indeed, which will soon be described, are still necessary to convert it into proper blood.

The blood is the common material of which all the tissues and all the organs of the body are built up. It is equally requisite to the formation of the most tender and delicate membrane, and to the construction of the hardest bone: it gives origin alike to the mildest and blandest fluid, as the saliva and milk, and to the most active and irresistible, as the gastric juice. It furnishes the new particles by which the capillary arteries, the masons and architects of the system, build up their different structures in the different parts of the body according to the wants of the economy. It affords the necessary stimulus to the great systems, especially the nervous and the sanguiferous, by which they are excited to the due performance of their functions—a stimulus, the interruption of the supply of which, even for a moment, causes them to languish, and the protracted interruption of which stops the machinery, and totally destroys it.

It is not wonderful, therefore, that life, even in the estimation of those who are entirely ignorant of anatomy and physiology, should be thought to reside especially in the blood. It is not won-

derful that this opinion should have influenced the common language of mankind; that the term vital should, by common consent, be given to this important fluid, and that, with the word blood, the idea of life should be indissolubly associated. For these reasons, as well as on account of the most important part which the blood performs in every function of the animal economy, and the curious and interesting facts which have been ascertained relative to its composition, it is necessary that some account should be given of its nature and properties, although the full detail would occupy much more space than can be allotted to it in the present treatise.

Every one is acquainted with the appearance of the blood as it flows from a wounded blood-vessel: issuing from such a vessel, it is seen to be of a red colour, and of a thick and tenacious consistence. To a person who merely sees the stream as it flows, or who examines a mass of it collected in a cup, immediately after it is removed from a vein, two circumstances appear pretty evident; first, that it is a fluid substance; and secondly, that it is perfectly homogeneous in its nature. And yet it is not a fluid; or, at least, it does not long remain a fluid, for, in a few minutes, a large portion of it is converted into a tolerably firm solid; and, instead of being homogeneous in its nature, it is by far the most complicated substance in the whole body. Moreover, the mode in which its constituent parts are united is peculiar, and, in some important particulars, resembles nothing else with which we are acquainted. In describing this highly curious and important substance, we shall first of all consider its physical; secondly, its chemical; and thirdly, its vital properties. Although, at first view, it may not appear to be a natural arrangement to describe the properties of a substance without previously stating what are its component parts, yet the constitution of the blood is so peculiar, that we think even the account of the individual substances which enter into its composition will be more intelligible, and, therefore, more interesting, to the general reader, by the adoption of the order we propose to follow.

Of the Physical Properties of the Blood.

Among the physical properties of the blood may be enumerated its consist-

ence, its colour, its specific gravity, and its temperature.

Of the Consistence of the Blood.

The blood, when it first flows from the vessels which contain it, is a thick, viscid, and tenacious fluid. All these properties vary in different species of animals; and in the same animal at different periods, according to age, sex, health and disease. Soon after it has issued from its vessels, its consistence changes exceedingly, and it is converted, as has been stated, partly into a firm solid, and partly into a thin fluid. The means by which this change is *prevented*, as long as it is contained in its proper vessels, and by which it is *accomplished*, as soon as it is removed from them, belong to its vital properties, and will be explained hereafter.

Of the Colour of the Blood.

The blood in all animals is essentially the same, although it differs very considerably in colour in different classes. An equal difference prevails in the colour of the muscular fibre in different species of animals; yet all physiologists are agreed that there is no difference in the nature of the muscular fibre from the lowest animal, in which it can be traced, up to the highest. "Some animals," says Mr. Hunter, "have not that part of the blood which gives it the red colour, but the other parts, as the lymph and serum, as far as I yet know, are the same in all."

The nutritive fluid of the lower animals, then, although it be perfectly colourless, must still be considered as proper blood. In the insect this fluid is transparent: in the caterpillar it is of a greenish colour: in the internal vessels of the frog it is of a yellowish tint: in the higher classes of animals it is of a red colour; but even in these it is red only in certain parts of the body: thus, in fish it is red in the vital organs, as the heart, the liver, the branchiæ or gills, while the main bulk of the body, which consists of muscles, receives only a colourless fluid; and even in man there are parts of the body, the vessels of which are too minute to admit the red particles, as in some of the tunics of the eye, in the tendons and aponeuroses of muscles, and in the serous membranes. It is of the deepest colour in quadrupeds, although in some birds it is nearly as deep as in any class. It is deeper in some species than in

others: it is deeper, for instance, in the hare than in the rabbit. Even in the same species there is considerable diversity, and especially in man, upon which diversity many physiologists think the different temperaments, and in some measure, also, the various races of mankind, depend. Even in the same individual it is different at different periods, according to age, to disease, and even to different species of disease, so that, on the one hand, the pallidness, and, on the other, the duskiness of the skin, and the dark and livid colour of the cheeks, are alone sufficient to disclose to the physician the existence of some of the most formidable maladies to which the human body is subject.

It will be seen hereafter that the higher animals possess what is termed a double circulation: that is, one circulation from the heart to the lungs, and from the lungs back to the heart again; this is called the pulmonary circulation: and another circulation from the left side of the heart to all the parts of the body, and from all the parts of the body back to the right side of the heart; this is termed the systemic circulation. Now, the colour of the blood contained in the two sets of vessels which belong to each of these two systems of circulation is extremely different: in the one set it is of a dark or Modena red: in the other it is of a light scarlet colour. The vessels which contain the dark-coloured blood are called veins: the vessels which contain the scarlet-coloured blood are termed arteries. The veins convey the blood to the heart: the arteries carry out the blood from the heart, and distribute it to all the parts of the body: the arterial blood is the proper nutritive fluid: the venous blood is that which remains after it has been subjected to the various processes of nutrition, and which is carried back to the heart, and thence to the lungs, in order to be renovated, that is, in order to be reconverted into arterial blood. The changes which take place in the blood, and which occasion this striking alteration in its colour, will be described in the proper place.

It has just been stated that arterial, in contradistinction to venous blood, is the proper nutritive fluid; and, indeed, it is absolutely essential, both to the sustenance of life, and to the excitement of the vital organs to the due performance of their functions. If the circulation of arterial blood through the brain be

stopped; if only venous blood be allowed to flow through its vessels, instant insensibility supervenes, and death follows in a few seconds. It is true, indeed, that venous blood is capable of nourishing some organs sufficiently to prevent them from perishing: an illustration of which is occasionally afforded by the peculiar disease of arteries, termed aneurism, which sometimes cuts off from a limb the supply of arterial blood: yet, in such cases, the member does not die, although it languishes, as all organs do languish, and many speedily mortify when they do not receive a certain quantity of arterial blood.

Of the Specific Gravity of the Blood.

The specific gravity of the human blood is estimated differently by different authors, probably because it differs in different individuals, and in the same individual at different periods. Taking water as 1000, the specific gravity of the blood may be stated to be about 1050: from this it may increase to about 1126. Haller stated its possible increase as high as 1527, but all modern inquirers are agreed in affirming that it has never been actually observed as high as 1126. The specific gravity is considerably altered by disease; the effect of disease is almost invariably to make it lighter: in one instance, on record, it was found as low as 1022. Dr. Davy states that arterial is lighter than venous blood: he estimates arterial at 1049, and venous at 1052. The more perfect the organization of the blood, or the higher the degree of vitality it possesses, the greater appears to be its specific gravity: for, in the higher order of animals, and in man, it is heavier than in the lower, and the effect of disease, as has just been stated, is, to lessen its weight.

Of the Temperature of the Blood.

The temperature of the blood differs considerably in different classes of animals. In cold-blooded animals and some quadrupeds the temperature is considerably higher than in man. In the sheep it is 102° or 103° , but of all animals it is highest in birds; in the duck it is 107° ; and in man it is about 98° . It is said to be warm in proportion as it is near the heart. It is the general opinion that the blood of the artery is warmer by one degree than that of the vein. Disease is capable of affecting its temperature very considerably. In the cold fit of ague it has been

observed as low as 94° ; and in some ardent fevers it has risen as high as 102° , or even, as some affirm, still higher. From some experiments of Hunter, he concludes that a moderate degree of inflammation is capable of raising it 4° , and an intense inflammation 7° above the natural standard. The power of all animals to maintain, with little variation, the temperature at which the functions of their economy are performed in the best manner, whatever be the temperature of the medium by which they are surrounded, has already been largely stated. But man, although, as has been shown, his natural temperature is much less than that of some other animals, has by far the greatest power of maintaining steadily his own temperature under intense degrees of cold, and still more intense degrees of heat.

Of the Chemical Properties of the Blood.

It has been stated that the blood is an exceedingly compound substance, consisting of many different ingredients which are held in union in a manner, in some respects peculiar; and that, when it first flows from the vessel, and for some time afterwards, it is fluid. At a certain period this fluid separates into two distinct parts—into a solid mass, and into a yellowish fluid in which the solid mass swims. The solid portion is termed the clot, or the crassamentum: the fluid portion is called the serum, and the process by which the separation takes place is denominated coagulation.

The period at which coagulation takes place varies according to a great variety of circumstances, which are chiefly interesting to the physician, and into the detail of which it is not necessary to enter at present. It is sufficient to observe, that the process commences in about three minutes and a half after the blood leaves the vessel, and is completed in from twelve to fifteen or twenty minutes. It is commonly stated that, upon an average, venous blood, in a state of health, is coagulated in seven minutes.

When first drawn from its vessel it possesses a temperature evidently greater than that of the atmosphere. As long as it retains its heat, an aqueous vapour arises from it, which is called its halitus, and which possesses a foetid odour, which is much stronger in carnivorous than in granivorous animals. In the process of coagulation the blood is changed from a fluid into a solid, and, as in other pro-

cesses in which a similar conversion takes place, there is an absolute extrication of caloric: for if, during the formation of the clot, a thermometer be moved first into the coagulated and afterwards into the fluid part, it will indicate a difference in the temperature of 6° ; and if the system be suffering under a state of inflammation, of 12° . The relative proportions of the two constituent parts of the blood, the crassamentum and the serum, is variously estimated. It is difficult to obtain an accurate result, because the separation is incomplete, a portion of the serum always remaining attached to the crassamentum, while the proportion itself varies considerably in different individuals, and in the same individual at different times; but, as a general average, it may be stated that the crassamentum amounts to about one-third of the weight of the serum.

The crassamentum, after a certain time, further separates into two different parts, into a solid substance of a yellowish white colour, and into a red mass, to which the colour of the blood is owing. When the first substance is examined, it is found to be a solid of a considerable consistence, soft, yet firm, elastic, tenacious, so disposed to assume a fibrous arrangement as occasionally to form a net-work of fibres, and bearing in its general aspect, as well as in its chemical relations, a striking resemblance to pure muscular fibre, that is, to muscular fibre deprived of its enveloping membrane and of its colouring matter. This substance is designated by several names,—gluten, coagulable lymph, fibre of the blood, fibrin: the last is its most appropriate and, now, most common name. The second constituent of the crassamentum, the red matter which separates from the fibrin, consists of innumerable minute bodies of a rounded or globular figure, and which are termed the red particles or globules.

The specific gravity of the fibrin is greater than that of the serum, in consequence of which the former floats in the latter; yet the surface of both substances is always found nearly on a level, so that their specific gravity cannot greatly differ. On the contrary, the red particles are heavier than the fibrin, whence they subside during coagulation to its lower surface, forming the bottom of the clot.

The fibrin is by far the most impor-

tant part of the blood: it is found in animals in which the red particles are absent: coagulation depends upon it: it forms the solid structures of the body: it constitutes the basis of muscle, and in the lower animals, which are destitute of the red particles, it probably performs the function of muscle.

Of the red particles, whatever be their nature and structure, it may safely be said that they are the least important part of the blood, although they have obtained the greatest share of attention, and have been the subject of innumerable observations and experiments. In many animals they are entirely wanting, and in all they are absent in some parts of the body.

When the smallest drop of blood is examined, the number of these particles contained in it appears to be countless: their magnitude is so minute that they can be distinguished only by the microscope. Their figure and bulk are different in different species of animals: in the reptile, the fish, and the bird their form is elliptical: in all the mammalia and in man they are circular. In the human blood the best observers are agreed in representing them as circular, flattened, transparent bodies, with a dark spot in the centre, which is owing not to a perforation, but to a depression. They consist of an external envelop and of a central nucleus: the external envelop is red, and gives the red colour to the blood. The internal nucleus is colourless; the nucleus is independent of its envelop, for when the latter is destroyed the nucleus retains its original form. The nucleus is much smaller than the envelop, being, according to Dr. Young, only about one-third the length, and one-half the breadth of the entire particle. MM. Prevost and Dumas, who have investigated this subject with extreme care, and have arrived at several highly curious and important results, state that, in their view, the blood consists essentially of serum, in which are suspended a quantity of red particles: that each of these particles consists of an external red vesicle, which incloses in its centre a colourless globule: that during the progress of coagulation the external vesicle bursts and allows the central globule to escape; that, on losing their external covering the central globules are attracted together; that they are disposed to arrange themselves in lines and fibres; that these fibres

form a net-work, in the meshes of which they mechanically entangle a quantity both of the serum and of the colouring matter; that these latter substances may be removed by draining and by ablation in water; that when this is accomplished there remains only pure fibrin: that, consequently, fibrin consists of an aggregation of the central globules of the red particles, while the general mass that constitutes the crassamentum, or clot, is composed of the entire particle. It is further stated by these distinguished physiologists that the colouring matter of the external envelop consists of a union of a peculiar animal substance of a gelatinous nature with the peroxide of iron.

Of all animals, the red particles are largest in the skate. In fish in general they are larger than in any other class. After fish, their magnitude is greatest in reptiles. In birds they are much smaller; and in man they are smaller than in any other animal. The estimation of their diameter in the human blood by different observers varies greatly. According to

Bauer, without colouring matter,	$\frac{1}{1700}$ part of an inch.
Bauer, with ditto,	$\frac{2}{3000}$
Wollaston,	$\frac{1}{5000}$
Young,	$\frac{1}{8000}$
Kalter,	$\frac{1}{4000}$
Prevost and Dumas,	$\frac{1}{4076}$
Hodgkin,	$\frac{1}{3000}$

The blood of different animals differs exceedingly in the relative quantity of the red particles it contains: the number appears to bear an exact ratio with the temperature of the animal: the higher the natural temperature the greater the proportion of particles: arterial contains a much greater proportion of them than venous blood.

We have seen that innumerable particles are found in the chyle, and that the chylous particles are colourless. It is stated that the magnitude of these chylous particles is precisely the same as that of the central globule of the red particle of the blood. It is supposed that the chylous, colourless particles obtain their colour, and consequently their external envelop upon which it depends, in the lungs: it is, therefore, in this organ, that the process of digestion is completed, the chyliferous being here completely converted into sanguiferous particles.

Of the Serum of the Blood.

When the fibrin separates from the

crassamentum or clot, it floats in a fluid which is termed the serum. Serum is a transparent homogeneous fluid of a light straw colour tinged with green, of saline taste and adhesive consistence. Its most remarkable and characteristic property is that of coagulation by heat and by certain chemical agents. At a temperature of 160° it is converted into a white and opaque substance, of tolerably firm consistence. In this state it exactly resembles white of egg when hardened by boiling, and is found to be of the same nature, whence it is termed albumen.

The proportion of serum to the crassamentum differs exceedingly in different species of animals, and in the same animals at different times, according to the state of the system. It appears to have a close relation to the strength and ferocity, or the weakness and gentleness of the animal, being, for example, much smaller in quantity in all the carnivora than in the sheep, the hare, and other timid animals. It is much increased in certain diseases: it is the fluid which is poured out into the different cavities in dropsy, while in some inflammatory diseases its quantity is considerably diminished.

With regard to its chemical properties, it contains a quantity of uncombined alkali, for it converts the vegetable colours to green. It holds in solution various earthy and neutral salts, which exist in it with remarkable constancy, and nearly in the same proportion under all circumstances. On analysis, it is found that 1000 grains of serum yield rather more than nine grains of saline matter: of these, about six and a half consist of muriate of soda, combined with a small quantity of muriate of potash, about one and a half of subcarbonate of soda, with a minute quantity of sulphate of potash, together with the phosphates of lime, iron, and magnesia. Sulphur is also present in it, as is proved by its tarnishing silver and blackening the acetate of lead. It is supposed that the saline matter contained in the serum of the blood stimulates the nerves of the heart, and thus contributes to the contraction of its muscular fibres; that it aids in the operations of the secreting organs; that it contributes to the process of digestion, and that it affords the materials of which the earthy portion of the bones is formed.

Of the Serosity of the Blood.

If, when, by the application of heat or

of some chemical agent, the whole of the serum is coagulated into a solid mass, this mass be cut into small pieces and placed in the mouth of a funnel, a fluid drains from it which is called the serosity of the blood, or, if the mass be subjected to pressure, the same fluid may be obtained from it. The serosity, then, is the watery fluid obtained from the serum after its coagulation, and it is this fluid which is observed to issue from meat at table when cut into, as mutton and beef, and which is then called gravy.

Such are the individual substances which enter into the composition of the blood. All these substances, like those which constitute animal matter in general, are resolvable into the ultimate elements of carbon, oxygen, hydrogen, and azote. Tables are given in the works which treat of animal chemistry, showing the respective proportions in which these elements combine to form albumen, fibrin, jelly, and so on; but these need not be quoted here.

Thus it appears, from the preceding account, that the different appreciable and known constituents of the blood are the halitus; the crassamentum, which consists of fibrin and of red particles; the serum, which is composed of albumen, and of a watery fluid termed the serosity; and of various earthy and saline substances held in solution by the serum.

Of the Vital Properties of the Blood.

The blood not only maintains the life of all the other parts of the body, but it is itself alive. Some obscure notion of this kind prevailed at a very early period, and is alluded to by Hippocrates. Harvey formed a clearer conception of the truth, and Hunter states the fact distinctly, and in adducing the proofs of it which occurred to him, observes, that he had long suspected that life was not wholly confined to substances endowed with visible organization, and capable of spontaneous motion. Since the time of Hunter the opinion has been slowly but steadily extending among physiologists, and the evidence of its truth may now be considered as completely satisfactory.

1. There can be no evidence that a substance is alive but that it exhibits the phenomena which have been stated to be peculiar to, and therefore characteristic of, life. Whatever be, in other respects, the condition of a body which

exhibits truly vital phenomena, it must be admitted to be a living body. Now, the blood exhibits several of the most characteristic properties of life. In the first place, it is capable, like other living bodies, of resisting, within a wide range, the ordinary influence of physical agents. Many illustrations have already been given of the extraordinary power of the living body to resist intense degrees of heat and cold. Among these was mentioned, and we must again advert to it, on account of its striking analogy to certain phenomena exhibited by the blood, the preservative power of the egg. It is well known that the egg possesses the power of self-preservation for several weeks, although exposed to a degree of heat which would certainly occasion the putrefaction of dead animal matter. During the period of incubation the egg is kept at a heat of 103° , the hen's egg for three, that of the duck for four weeks: yet when the chick is hatched, the entire yolk is found perfectly sweet, and that part of the albumen, or white, which has not been expended in the nourishment of the young animal, is also quite fresh. It is found that if the preservative principle be destroyed, as it may be instantaneously, by passing the electric fluid through the egg, it becomes putrid in the same time as other dead animal matter.

Its power of resisting cold is proved to be equally great by several curious experiments of Hunter, which were so managed as to show, at the same time, both the power of the vital principle in resisting the physical agent and the influence of the physical agent in diminishing the energy of the vital principle. Thus he exposed an egg to the temperature of 17° and 15° of Fahrenheit: he found that it took about half an hour to freeze it. When thawed, and again exposed to a cold atmosphere, it was frozen in one half the time, and when only at the temperature of 25° . He then put a fresh egg, and one that had previously been frozen and again thawed, into a cold mixture at 15° : the dead egg was frozen twenty-five minutes sooner than the fresh. It is obvious that, in the one case, the undiminished vitality of the fresh egg enabled it to resist the low temperature for so long a period: in the other case, the diminished or destroyed vitality of the frozen egg occasioned it speedily to yield to the influence of the physical agent. Now,

precisely the same results were obtained in analogous experiments with the blood. On ascertaining the degree of cold and the length of time necessary to freeze blood immediately taken from the blood-vessel, he found that, as in the egg, a much shorter period and a much less degree of cold were requisite to freeze blood that had previously been frozen and again thawed, than blood recently taken from the vessel. It is reasonable to infer that this difference arises from the same principle; the vitality of the recent blood, being comparatively undiminished, enables it to resist the cold longer than blood the vital energy of which has already been partly exhausted by previous exposure to the influence of this physical agent.

2. Hunter adduces some facts to show that the blood, like other living substances, originates motion and action. We know that if a living egg be placed under a hen, or even exposed for a certain time to a degree of artificial heat equal to that in which it is maintained during incubation, certain motions or actions spontaneously arise within it which terminate in the development of the chick. This illustrious physiologist, from certain observations which he was the first to make, was led to the conclusion that an analogous process occasionally takes place in the blood. If in the living body blood be effused from its vessels, either upon the surfaces of organs or into cavities, it solidifies without losing its principle of life: it is not correct to say that the blood coagulates under such circumstances, for the term coagulation should be confined to the solidification of the blood without the body. If the solid thus produced be examined some time after its formation, it is found to abound with blood-vessels. Some of these vessels can be distinctly traced from the surrounding living parts into the solid: others cannot be traced from these parts. Those, the origin of which could not be found external to the solid, were supposed by Hunter to be formed within it. It is obvious that if this were really the fact, such a solid would commence an action which would terminate in its organization—an action perfectly analogous to that by which the incubated egg commences a series of movements which terminate in the development of the chick; an action which no substance could possibly originate unless it were endowed with life. It must be confessed, however, that it is doubtful

whether the fact be correct, especially as thus stated. There is no doubt that the blood thus solidified within the body becomes organized. The point unsettled is, whether the vessels which organize it shoot into it from the living parts in contact with it, or originate, partly at least, within itself: the doubt, however, does not interfere with the present argument: a dead substance, thus surrounded by living parts, does not become organized; the blood does, and the argument is that, therefore, it must itself possess vitality.

3. An argument in favour of the vitality of the blood more conclusive, because the fact upon which it is founded is unquestioned and unquestionable, is derived from its fluidity. We know that, while circulating within its vessels, it is maintained in a fluid state. It could not circulate, it could not readily divide itself so as to permeate through the constantly diminishing tubes of the arteries, and the minute branches of the veins, unless it were fluid. All the actions of the economy would instantly cease, all the wheels of the machinery would be clogged and stopped, were the mass in the living body to become solid, or even to approach to the solid state. And yet its power of becoming solid is a property so essential to it, that without it all its other properties would be useless, because it is upon this power that the construction of the solid textures entirely depends. We have seen that its tendency to assume a solid state is so great that, when removed from the living vessel, a large portion of it is converted into a firm solid in a few minutes; and that, even within its vessel, if any circumstance happen to interrupt the circulation for a considerable time, it is exceedingly apt to become solid, and to plug up the channel. It is probable that slow motion increases its consistence in an appreciable degree: it is certain that absolute rest greatly promotes and hastens its solidification. Some of the most important and essential actions in the economy appear to depend upon this property, for the arrangement of the secreting vessels in all the organs of secretion is uniformly and strikingly such as to ensure an exceedingly slow motion of the blood through them. It was necessary, then, in constructing the blood, to preserve the balance between its fluidity and solidity so nicely, that, while all the purposes of the economy should be secured, its actions should not

be impeded by the very instrument that was essential to them. A fluid must be formed capable of becoming solid with ease and certainty; and at the same time capable of maintaining its fluidity with the like ease and certainty. Now, a substance endowed with properties so opposite, and whose continuity of properties is so constantly called into play, and is so essential to the ultimate purpose of its action, is found in nothing purely mechanical: human ingenuity can construct no machinery analogous to it: it is found only in the mechanism of life, and the property is so peculiar to life, and so distinctive of it, that we have no other resource than to refer all the particular facts of this kind that are met with to the principle of life, and to say that they depend upon a vital principle. We cannot avoid some such modes of expression, and in fact this is the language uniformly employed by all physiologists. When they observe that the blood while it circulates in the living vessel maintains its fluidity, but becomes solid almost immediately after it is withdrawn from the vessel; when they observe that it is not the cessation of its circulation that causes its solidification, since, on making the experiment, they find that if it be kept at the same temperature as in the living body, and made to circulate with equal rapidity through a dead tube, it equally becomes a solid, they say it is maintained in a fluid state by the principle of life. We ought, however, never to forget that all expressions of this kind amount to no more than the general statement of the fact that the phenomena in question are uniformly found in connexion with the condition of life; and still less ought such language to divert our attention from, or render us insensible to, the beauty and wisdom of adjustments which, perhaps, we do not perceive to be mechanism only because the mechanism so much surpasses in delicacy and perfection any with which our gross senses have made us acquainted.

4. The blood must be a living substance because it is capable of dying. It is capable of sudden death; for if the electric fluid be passed through it, it is killed instantaneously, as has been stated already in a former part of this treatise. But it may be said to undergo the process of natural death, a process which has already been described under the name of coagulation. When this process is attentively examined it will be found to

be a very curious operation, bearing little analogy to any other with which we are acquainted, and the cause of which there is considerable difficulty in assigning. Perhaps the process which bears the greatest resemblance to it is the coagulation of albumen; but there is this essential difference between the two,—that albumen does not coagulate of itself, but only on the application of heat or of some chemical re-agent; whereas the blood coagulates spontaneously. Little light is thrown on the subject by considering the different circumstances in which the blood is placed when contained within its vessel and when withdrawn from it. In the one case, it is in constant motion, in the other it is in a state of rest: in the one case it is excluded from the air, in the other it is exposed to it: in the one case it is maintained in an equal and somewhat high temperature, in the other it is placed in a temperature considerably lower. Accordingly, rest and exposure to the atmospheric air and to cold have been assigned as the causes of the coagulation of the blood.

But that rest alone is not sufficient to cause the coagulation of the blood, is evident, on the one hand, because one of the most common methods of obtaining a coagulum is by constantly stirring the blood as it flows from a vein; and, on the other, because when a tourniquet is applied to a vessel the blood contained in it remains fluid: moreover in fainting fits, however long continued, in which the circulation appears to be stopped, coagulation does not take place.

That exposure to atmospheric air is not essential to coagulation is equally certain; for Mr. Hunter proved that coagulation takes place *in vacuo*; and we have seen that it occurs in situations from which the air must necessarily be excluded; in living vessels, in various cavities of the body, and on its surface: thus, when a blow has been received on the eye, causing the appearance which is termed ecchymosis, if, in about half an hour after the blow has been received, a lancet be plunged into the wound, the blood will be found coagulated.

Neither is cold necessary to the process. The temperature of the fish is about 60°: if the blood of the fish be removed from the body, and brought into a temperature of about 70°, it immediately coagulates. If blood, taken from a warm-blooded animal, as the rabbit, be frozen, and afterwards thawed,

it will be found to be perfectly fluid. Numerous experiments show that the blood most readily coagulates at its natural temperature (98°); that it coagulates most slowly between 60° and 90°; and that below 38° and 32° it does not coagulate at all, but remains fluid. While it is evident, therefore, that neither rest, nor exposure to atmospheric air, nor cold, are essential to this curious process, yet all observation and experiment agree in showing that each promotes it in a considerable degree.

These observations abundantly attest how little the process of coagulation is dependent on physical agents: there are other phenomena connected with it, which show how closely it is related to the actions of life—phenomena which prove that the vitality of the blood increases or diminishes with the vitality of other parts of the body. The blood, when drawn from its vessel, does not instantly die or coagulate. By observing the length of time consumed in the process, we are able, in some sort, to measure the degree of vital energy it possessed. It is found that in diseases which depend on a preternatural energy of vital action, as in inflammation, the blood coagulates much more slowly than in a state of health, while the coagulation itself is more perfect; and, on the contrary, that in diseases which depend on a diminution of the vital energy, as in certain fevers, it either coagulates much more rapidly, or does not coagulate at all: because, in the first case, it possesses the vital principle in a higher degree than natural, and, therefore, resists longer the influence of the physical agents to which it is exposed; and, in the second case, it possesses the vital principle in a less degree than natural, and, therefore, sooner yields to the influence of those agents. A phenomenon connected with the coagulation of the blood, of great importance to the physician, depends on this principle: namely, the formation of what is termed the “buffy coat,” an appearance in the blood which denotes inflammatory action in the system, and the presence of which affords an invaluable guide in the treatment of disease. The terms “buff” or “size” are employed to denote that state of the crassamentum when its upper part contains no red particles, but exhibits a layer of buff-coloured substance, lying on the top of the red clot. In this condition of the blood, the red particles

sink to the lower part of the clot before the coagulation is completed, and, therefore, the upper surface of the clot is colourless: at the same time, the whole of the coagulated portion is much firmer than natural. The red particles have time to subside before the coagulation is complete, because the coagulation is slower; and it is slower because, in the morbid condition of the system of which this buffy appearance is the sign, the blood possesses a higher degree of vitality than it does in a sound state. The truth of this opinion, which had long been prevalent among physiologists and physicians, is proved in the clearest manner by a very simple but beautiful series of experiments, instituted by Mr. Thackrah. These consist in receiving blood taken from the vessels of a living animal, in a full and uninterrupted flow, into different cups, and noting the time at which coagulation commences in each. For example, blood was taken from a horse at four periods, about a minute and a half being allowed to intervene between the filling of each cup. In the first cup coagulation began in eleven minutes, ten seconds: in the second cup, in ten minutes, four seconds: in the third cup, in nine minutes, thirty-five seconds: in the fourth cup, in three minutes, twenty seconds. In another experiment, blood was received from the vessels of a slaughtered ox into three cups—No. 1. being filled in the first flow; No. 2. about three minutes afterwards; No. 3. a short time before the death of the animal. Coagulation commenced in No. 1. in two minutes, thirty seconds: in No. 2. in one minute, thirty-five seconds: in No. 3. in one minute, ten seconds. In a similar experiment coagulation commenced in the first cup in two minutes, ten seconds: in the second in one minute, forty-five seconds: in the third, in thirty-five seconds. Similar phenomena are observed to take place in the human subject. Blood, to the amount of about one pint and a half, was taken from the arm of a woman labouring under fever: a portion of it received into a cup, on the first effusion, remained fluid seven minutes; a similar quantity, taken immediately before tying up the arm, was coagulated in three minutes, thirty seconds. Of blood taken, as in the preceding experiment, from the arm of a man, the first portion began to coagulate in seven minutes; the last in four. The vitality of the system, and, together with it, the vitality of the blood,

being diminished by each successive abstraction, this fluid coagulated, that is, its vital principle become totally extinct sooner, and sooner in proportion as it was previously weakened.

Other experiments of Mr. Thackrah, perhaps still more interesting, go to establish, in the clearest manner, that vitality is communicated to the blood, or, at least, is maintained in it through the medium of the nervous system, the nervous influence being transmitted to it by the nerves of the vessels that contain it, the arteries and veins. Thus a portion of a vein, in a living animal, was included between two ligatures: this portion was allowed to remain in its natural situation: at the end of ten minutes the blood it contained was not coagulated. Again, a portion of a vein was included between two ligatures in a living dog: it was then removed from the body, and immersed in water at the temperature of 98° : the blood it contained was not coagulated at the end of an hour. On the other hand, a dog having been killed, a portion of a vein was immediately taken from its body and plunged into water, which was maintained for two days at the temperature of between 90° and 100° . At the end of this period a quantity of blood was made to flow from the vein of a living dog into this dead vein: the blood being secured by ligature in this dead vessel, was then immediately immersed in water, at the temperature of 98° : at the end of a quarter of an hour, the blood was found firmly coagulated. Thus, blood contained in a living vessel did not coagulate in the space of an hour: that inclosed in a lifeless vein coagulated in one-fourth of the time.

It has already been stated that coagulation, the process by which the blood is converted into a solid when abstracted from its vessels, is totally different from that by which it becomes solid, within the living vessel, or within the living system: that the first may be considered as its natural death; but that, on the second, depend some of the most important processes of the living economy. This may be illustrated very beautifully by attending to the process by which a wound heals. When a living solid is wounded, a number of its blood-vessels are divided; a quantity of blood is poured out into the cellular tissue that surrounds the wound; the red particles soon disappear, being taken up and removed by the absorbent vessels: an

adhesive matter remains which glues together the edges of the wound: this adhesive matter is the fibrin which gradually becomes organized: according to the received opinion, by the elongation of the minute blood-vessels of the immediate neighbourhood which shoot into the interior of the effused substance; according to Hunter, partly by this process, and partly by the origin of new arteries and veins which are formed within the effused substance, and which springing from it unite with the elongated vessels of the parts in the immediate neighbourhood: the effused adhesive matter, thus acquiring blood-vessels, and receiving a regular supply of blood, becomes a true and proper part of the living body, and exercises its appropriate functions in the economy. This process is called by surgeons, healing by adhesion: it depends essentially upon the solidification and adhesiveness of the fibrin, and without this property of the blood no loss of substance could be reproduced; no part of an injured organ could be repaired; no surgical operation could be performed; no wound in a blood-vessel could heal; and, consequently, the slightest cut must prove fatal.

Of the total Quantity of Blood in the Body.

The total quantity of blood in the body it is difficult to ascertain: the data on which the common calculations are made are uncertain—only approximations to the truth can be obtained. Haller estimates that, in the adult man, the blood may constitute about one-fifth part of the weight of the whole body. According to this calculation, a body weighing 150 pounds would contain about 30 pounds of blood: of this it is supposed that somewhat more than three-fourths are contained in the veins, and only one-fourth in the arteries. The quantity of blood in young animals is proportionably greater than in the old, or the adult, because, in the former, the body is not only to be sustained but enlarged, and many of the organs to be completed. In small and weak animals there is less in proportion to their size than in the larger and more muscular: in wild animals there is more than in the tame, and in the active more than in the sedentary. The quantity in different parts of the same animal is always in proportion to the importance of the organ: thus there is incomparably

more in the brain and stomach than in the skin and bones.

Of the Circulation.

Having thus explained the formation of chyle from the aliment, and traced it to its conversion into true and proper blood in the lung; having described the several component parts of the blood, and given an account of the properties of each, we now proceed to the consideration of the mode in which this vital fluid is distributed to the different parts of the body. This brings us to the subject of the circulation, in treating which, in conformity to the plan of this treatise, we shall first of all consider the apparatus by which the function is performed, and afterwards the function itself.

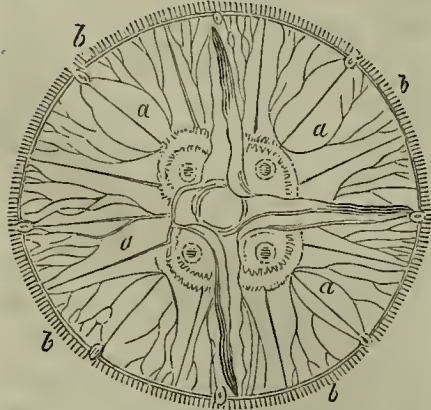
Of the Apparatus of the Circulation.

The circulation consists in the transmission of the nutritive fluid from a given point to the different parts of the body; and from the different parts of the body back to that point again. It is only when such a circle is performed that there is a true circulation. In order to carry on a circulation, a great number of organs is required, the possession of which is perfectly inconsistent with the simplicity of structure by which the lower classes of animals are distinguished. Wherever there is a true circulating system there is a complexity and perfection of organization, which gives to the creatures that possess it a high place in the animal scale: vast tribes of beings that occupy the lower part of the scale are destitute of every trace of it.

The necessity of a circulation exists only in animals of a certain structure. Whenever the nutritive fluid is elaborated in a special and isolated organ, there must be some means of conveying it from that organ to the other parts of the body: but where the entire body consists of one extended stomach there can, of course, be no need of a circulation. In almost all the orders of zoophytes the organization is thus simple. The infusoriæ, the polypes, the inhabitants of corals and sponges are composed of a uniform gelatinous substance, every part of which is constantly impregnated with its nutritive fluid, and is endowed with the power of supporting the changes, whatever they may be, that take place in their system. But we have seen that the earliest trace of a distinction of

parts in this uniform substance consists in the formation of a cell, a cavity, a tube, or some other special organization to which the performance of the function of digestion is restricted. Whenever this is the case, whenever the stomach assumes the form of a distinct organ, or begins to be in any degree isolated, then canals are seen to branch off from it in order to convey the nutritive fluid from this isolated spot to the different parts of the body. These canals usually branch off from the digestive organ in a radiated manner, because the figure of all these lower orders being more or less circular, the nutritive fluid is conveyed, by this arrangement, in the directest mode, to the extremities of the body. Hence, the earliest rudiment of a vascular system consists rather in the formation of an intestine than a vessel. These radiated canals are, at first, not distinct tubes composed of a peculiar tissue, but, as far as can be ascertained, appear to be merely excavations formed in the homogeneous substance of the body. Canals of this kind are first distinguishable in some of the higher orders of zoophytes. Thus, in the medusa there are seen to spring from the stomach distinct channels which proceed in a radiating manner towards the margin of the body, and which there empty themselves into a circular vessel (*fig. 41*); but it is impossible, in these animals, to distinguish any tubes for conveying the fluid back again to the organ whence it issued, and, consequently, they cannot be considered as possessing a true circulation. Even in animals the structure

Fig. 41.



Medusa amita seen from below; *a, a*, radiating vessels; *b, b, b, b*, circular vessel into which the radiating vessels empty themselves.

of which, in many important particulars,

is considerably more advanced than that of the medusa, as intestinal worms, the rudiments of the vascular system present still more the appearance of ramifications of the intestinal canal.

The first distinct and certain vessel for the distribution of the nutritive fluid appears to be found in the insect. If the general mass of the body, in almost all the orders of this class, be examined with a microscope, it will be impossible to detect the least appearance of a blood-vessel, although minute ramifications of the tubes, called tracheæ, are abundantly manifest in every part: but there is placed along the back a distinct tube, in which alternate dilatations and contractions may be clearly discerned. This tube is called the dorsal vessel. It constitutes a thin membranous canal of a uniform size: it is well seen in the caterpillar (*fig. 42*): but in this insect

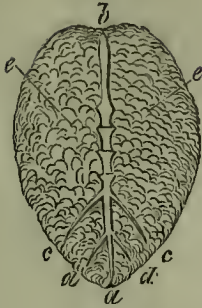
Fig. 42.



A part of the dorsal vessel of the caterpillar, with the fine ramifications of the tracheæ attached to it.

this canal is closed at both extremities, and no trace of a vessel in communication with it, either going to it or coming from it, can be discerned. It is remarkable, however, that it is completely surrounded by exceedingly minute ramifications of the tracheal tubes (*fig. 42*). If this vessel be removed from the body, or if the fluid it contains be coagulated by muriatic acid, the animal will continue to live, and does not appear to suffer any material inconvenience from its loss or obstruction. In the higher orders of insects, as the spider and scorpion, this vessel is more developed. In some of the arachnidæ, as in those spiders which are not covered with hair, it can be seen to pulsate with the naked eye; and, on careful examination, several vessels can be perceived to be given off by it, many of which can be traced to the branchiæ, and others are lost in certain bodies, called adipose (*fig. 43*): but the actual distribution of these vessels, and the route which the fluid they contain pursue, cannot be discovered with any

Fig. 43.



a, b, dorsal vessel of the spider; *c, d, c, d*, distinct branches given off from it; *e, e*, adipose bodies.

certainly, on account of the extreme delicacy of the vessels.

In a physiological view there is, at this point, a broad line of demarkation in the structure and functions of animals. On one side of this line, the lowest, are found all the orders of animals which are either altogether destitute of a vascular system, or in which there can be discovered only the faint and imperfect traces of it which have been described: and on the other all the orders of animals in which the vascular system is more developed; from those which possess a true circulation, however simple in form, to those in which the circulation is carried on in the most complicated and perfect manner. All the tribes of animals, on the one side, will be found to bear to each other a perfect physiological resemblance in the most important points of their organization, and to present to those, on the other side, equally important differences; these resemblances and differences being especially apparent in the essential functions of nutrition, respiration, and secretion.

The most simple form of a true circulation which is found actually to exist in the animal organization is that in which one set of vessels conveys the nutritive fluid to the different parts of the body, and from which another set of vessels, uniting with the first, returns the fluid to the point from which it originally set out. These two orders of vessels receive different names. The vessel which conveys the nutritive fluid to the different parts of the body is always called an artery: the vessel which returns the nutritive fluid from the different organs of the body, after it has circulated through them to the point whence it began to flow, is called a vein. The

apparatus requisite for the circulation, therefore, in its primitive form is extremely simple: there are required only two sets of vessels directly communicating with each other. Even so low down as the echinodermata, the highest order of zoophytes, Cuvier thinks he has discovered an example of this mode of circulation. In the holothuria, he describes a set of vessels which carry out the nutritive fluid to the different parts of the body, and which he, therefore, conceives to be analogous to arteries; and another set of vessels communicating with the first which return the fluid, and which, therefore, perform the function of veins. It is certain that some genera among the mollusca possess a circulating system thus simple.

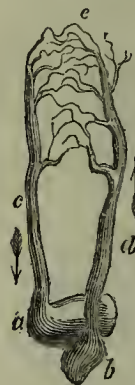
The next advancement in the organization of the vascular system is the construction of an organ which is usually placed between these two orders of vessels, and which, on account of its position, separating, and at the same time uniting, the two great systems of vessels, is called the central organ of the circulation. The name by which this organ is designated is the Heart. It is an engine placed between these two sets of tubes to assist in propelling the fluid they contain through them. It is a very important instrument in carrying on the circulation, but it is not essential to it, since a true circulation may exist without it: its presence, however, always implies a higher and more perfect, because a more extended and complicated, and, therefore, a more richly endowed organization. The first approach to the formation of such a central organ is observed in some of the more perfect orders of Vermes. In the *lumbricus terrestris*, or common earthworm, the communicating branches which run between the abdominal and dorsal vessels, exhibit several heart-shaped dilatations, which have been seen to contract with peculiar energy. In the crustacea these dilatations are more defined, and their action is more definite. The heart of the *astacus fluviatilis*, or cray-fish, is distinctly muscular, sends off several arteries both backwards and forwards, and when even wholly removed from the body, it may be observed to pulsate with very considerable activity. The state of the circulation, however, in all these orders of beings is very imperfectly understood; and the influence which a heart, so rudely constructed, can exert upon it cannot be estimated high,

Ascending another step in the scale of organization, we find it consisting of two bags or apartments which open into each other; between which there exists a free and constant intercourse. One of these apartments is destined to receive the blood from the vein; the other is intended to propel it into the artery. These two bags or apartments, like the two orders of vessels, receive appropriate names: that which receives the blood is always called an auricle; that which propels it forwards is always called a ventricle: from this account of their office it is obvious that the auricle must always be in communication with a vein, and the ventricle with an artery: the bag called the auricle always receives its fluid from a vein; the bag called the ventricle always propels its fluid into an artery.

The apparatus for the circulation, then, in an animal which possesses a simple heart, consists of a vein, of an auricle, of a ventricle, and of an artery; of a vein to convey the blood to the auricle; of an auricle to transmit the blood to the ventricle; of a ventricle to propel the blood into the artery; and of an artery to distribute the blood to all the parts of the body. The trunk of the artery when it springs from the ventricle, of course, is a large tube. If it perform its office perfectly, that is, if it convey the blood to all the parts of the body, to its most distant extremity, to its minutest portion, it must of necessity divide and subdivide, and subdivide again and again into branches of constantly decreasing magnitude, until at length they become exceedingly, we may almost say inconceivably, minute. When we consider that the finest point of the finest needle cannot pierce the vascular part of an animal without causing the blood to flow from the point pricked, we can have no difficulty in conceiving the extreme minuteness of the ultimate subdivisions of the vessel. These minute and ultimate subdivisions of the artery are called its capillary branches. The artery, then, may be said to arise from the ventricle of the heart by one large trunk, and to terminate in the organs by capillary branches. The vein divides and subdivides, in a similar manner, into branches equally minute, into capillary branches; but the course of the capillary veins is the reverse of the course of the capillary arterial branches. As the artery arises from the heart and terminates in the organs,

so the vein arises in the organs and terminates in the heart. Where the capillary branches of the artery terminate, there the capillary branches of the vein begin, and precisely there the two sets of vessels unite. Thus the capillary branches of the artery terminate in the organs by opening into the capillary branches of the veins. And thus we see how, by the course and communication of the tubes, the fluid they contain in moving through them must describe a perfect circle. In *fig. 44* we see a plan

Fig. 44.



c, trunk of the vein; *a*, the auricle; *b*, the ventricle; *d*, the trunk of the artery; *e*, capillary branches of artery and vein united.

of the circulatory apparatus as now described: *c* represents the vein, *a* the auricle, *b* the ventricle, *d* the artery, *e* the capillary branches of the artery and vein united. The points of the darts are in the direction of the current of the blood as it flows through the vessels. Let us trace that current from the points of union of the capillary vessels, in *e*. The capillary branches of the vein receiving the blood from the capillary branches of the artery convey it to the trunk of the vein, *c*; the vein transmits it to the auricle, *a*; the auricle sends it on to the ventricle, *b*; the ventricle propels it into the trunk of the artery, *d*, which by its capillary branches reconveys it into the capillary branches of the vein, and so the circle is complete.

Such is the circulation with a heart constructed on one of the most simple models: and such is the actual course of the circulation in a large class of animals, as in the mollusca. In this class the heart is said to be simple, and the circulation single: single because it describes only one complete circle.

Merely for the purpose of conveying the nutritive fluid to all the parts of the

body, and of keeping up a constant circulation of it through all the organs, the apparatus that has been described is sufficient. But the nutritive fluid, in describing this circle and in nourishing the organs on which it is spent, becomes deteriorated or deprived of its nutritive property. It is necessary for its renovation that it should be brought into contact with atmospheric air. For this purpose a new organ, which is called branchiæ or gills in the lower, and lungs in the higher orders of animals, is required, and consequently the apparatus of the circulation must be complicated by an additional instrument for conveying the blood to the branchiæ or to the lungs: hence arises the next complication in the structure of the heart or of the circulating apparatus.

The expedient by which this necessary purification of the blood is accomplished is by the communication of an additional artery to the apparatus, an artery which is made to convey the blood directly from the heart to the branchiæ, or lungs, and which, on account of its office, is called the pulmonary artery. The apparatus now consists of one vein, one auricle, one ventricle, and two arteries; namely, the pulmonary artery, and the primitive artery, which, in order to distinguish it from this new vessel, now takes the name of aorta. It is obvious that the pulmonary artery must always be placed between the heart and the organs of respiration, while the aorta must be placed between the organ of respiration and the general system of the body in order to receive the renovated blood from the respiratory organs, and to carry it out to the system. The structure of the apparatus of the circulation in the fish will illustrate this arrangement very beautifully.

In the fish (*fig. 45*) there is, first, the vein *a*, which conveys the blood to the heart; secondly, the auricle *b*, which receives the blood from the vein; thirdly, the ventricle *c*, which receives the blood from the auricle; and fourthly, *d*, a large artery which springs from the ventricle. Hitherto, then, the apparatus is precisely the same as that which has been already described as affording an example of it in its most simple form; but in that form this artery would convey the blood to the system. In the fish, on the contrary, it conveys it not to the system, but to the branchiæ, or the organs of respiration: it is, therefore, the pulmonary artery. From the

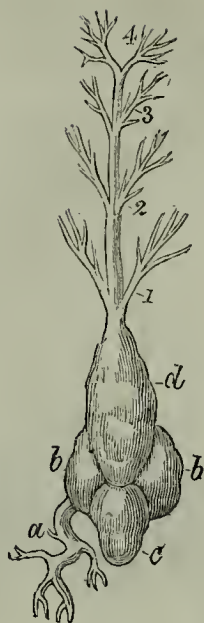


Fig. 45.

Heart of the Fish. *a*, the vein which returns the blood from the different parts of the body to the heart; *b*, the auricle into which the vein opens; *c*, the ventricle; *d*, the large blood-vessel arising from the ventricle; 1, 2, 3, 4, its branches, which go to the branchiæ.

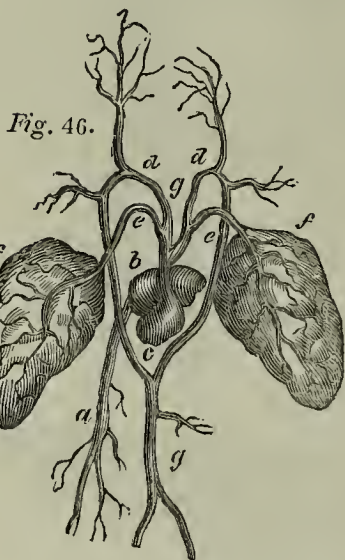
branchiæ the blood passes into a large artery, which is the analogous artery of the most simple model, because it is by its branches that the blood is conveyed to the body of the animal: this artery, therefore, is the aorta, or the systemic artery. The capillary branches of the aorta unite in the organs with the capillary branches of the vein, while the latter reconvey the blood back to the auricle of the heart; and thus, in the fish, the circle is complete.

In fishes, the size of the heart is exceedingly small in proportion to the bulk of the body. According to Tiedeman, it is but the $\frac{1}{331}$ th or $\frac{1}{768}$ th of the weight of the body, while in man it is $\frac{1}{166}$. The proportion of blood possessed by fishes is very small: they have, comparatively, few blood vessels, and even of these they have a small proportion of red and a much greater number of colourless vessels: hence their muscles are pallid, or white, and present a complete contrast to the deep red colour of the muscles in the higher animals.

In the next order of animals, that of reptiles, there is a peculiar modification of the pulmonic portion of the circulating apparatus: indeed, all the modification of this apparatus, from its most simple

to its most complicated model, has relation to the pulmonic portion, and arises out of the necessity of adapting the heart and its appendages to the peculiar mode in which the animal respire. Of this we shall perceive additional proof at every step of our subsequent progress.

In the frog (*fig. 46*) the heart consists of



Heart of the Frog. *a*, the vein; *b*, the auricle; *c*, the ventricle; *g*, the great artery, dividing into *e*, the pulmonic artery; and *d*, the aorta; *f*, the lung.

the same parts as those which have been described as constituting the circulatory apparatus of the fish. It has the same vein, *a*; the same auricle, *b*; the same ventricle, *c*; the same artery, *g*; but in the fish, this artery passes directly to the branchiæ: were the arrangement, therefore, perfectly similar in these animals, this artery would, in the frog, proceed immediately to the lung, *f*. Instead of this, however, it divides into two great branches, of which one, *e*, goes immediately to the lung, *f*, while the main trunk, *d*, passes on to the body. In this case, then, the branch *e* is the pulmonic artery, and the branch *d* is the aorta or the systemic artery. On inspecting this plan of the frog's heart, which is the model of that on which the heart of all amphibious creatures is constructed, it is obvious that only one half of the blood received from the ventricle is transmitted to the lungs before it is conveyed to the general system. Hence in these creatures only one half of the blood is aerated, and that which circu-

lates in their general system is always one half venous and one half arterial. The general constitution of all the creatures of this class is distinguished by very striking peculiarities. They are sluggish, languid, cold, inert, difficultly moved, and tenacious of life to a wonderful degree. They can bear all kinds of stimuli: they can bear to have their hands, legs, bowels cut away. Among other peculiarities of their constitution, they can live long without air: they will rise from time to time above water, if you will allow them: they can bear, again, to be kept under water, if you force them; but if they can live long under water, they can also live at least as long after you have cut off their heads or cut out their hearts.* As will be fully explained when we treat of the function of respiration, all these peculiarities are referable to the imperfect degree in which the blood is aerated; although in some of the higher orders of this class more blood is exposed to the air than in the frog, yet in a physiological view the structure of the circulatory apparatus is essentially the same in all. The heart in all these animals, though somewhat larger than in fishes, is still much smaller than in the higher classes: the weight of the heart in the frog is the $\frac{1}{24}$ th part of the weight of the body.

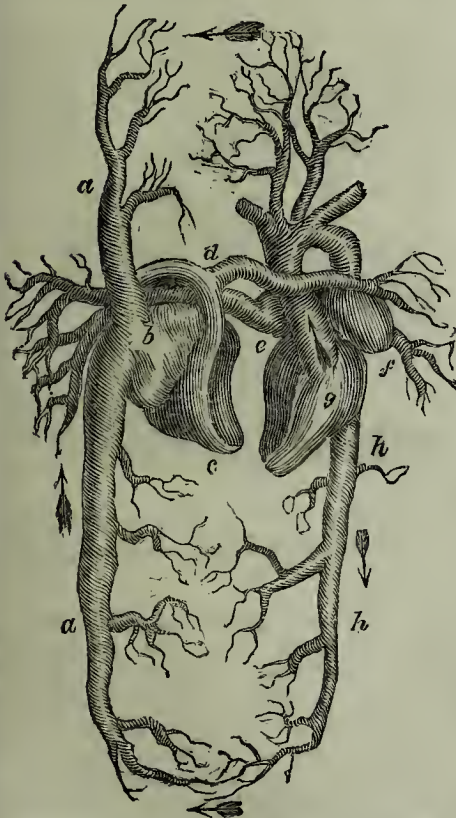
In the next class, that of birds, there is a prodigious advancement in the organization in general; and, in the circulatory and respiratory apparatus in particular. In the frog the lungs are small, and only one-half of the blood of the body passes through this little pulmonary system: hence the cold-bloodedness and inertness of the creature. In the bird, on the contrary, besides the proper lungs, there are additional bags for the extension of their respiratory system, and even all the great bones of its body are hollow and filled with air, and made subservient to the aëration of the blood: instead, therefore, of being cold-blooded like the reptile, the temperature of the bird is higher than that of any other animal; and, instead of being sluggish and inert, it is, of all creatures, the most quick and active. It will be readily conceived that the apparatus for the circulation must be essentially different in a creature which possesses a respiration, and a general constitution so strikingly contrasted to that of all the

* Bell's Anatomy, vol. i. p. 475.

classes below it. Accordingly, in the bird, the heart is no longer simple, it is highly complicated—as complicated as it is in the mammalia and in man: it is properly double: indeed, there is no physiological difference between its structure and that of the most perfectly organized animal: it has some peculiarities which are strictly connected with the peculiarities of its lungs, but these will be better understood when we treat of the apparatus of respiration. As we have now arrived at the most perfect model of the heart, and as its structure is in strict conformity to this model in all the ascending scale, instead of describing it as it is found in the bird, and in the mammalia, we shall describe it as it exists in man.

In man, and in all the higher animals, the heart is double; one heart is for the circulation through the lungs, the pulmonic: the other for the circulation through the body, the systemic. In (fig. 47) is given a plan of the heart,

Fig. 47.



sented in this figure as placed at some distance from each other: *a, a* represent the vein: it is now convenient to give this vein a name: on account of its great size in man, and in the higher animals, it is called the *vena cava*. There are, it will be seen, two veins, one above, and the other below: the one above brings the blood from the head and the superior extremities; it is called the superior *vena cava*: the one below brings the blood from all the lower parts of the body: it is named the inferior *vena cava*. The two *venæ cavæ* meet at *b*, and pour their blood into the auricle *b*, which must now be distinguished by the term *right*. The right auricle is partly formed by the dilatation of these veins; but there is, also, a portion of it which is strong and muscular, and which is commonly described as forming the proper auricle. The *right auricle* opens into *c*, the *right ventricle*, which is larger than the auricle, and possesses much thicker and stronger muscular walls. From the right ventricle springs the *pulmonic artery*, *d*, which divides into two large branches, one of which goes to the right lung, and the other to the left. This, then, is the apparatus for the right side of the heart, for the pulmonic or the lesser circulation: all this part of the apparatus merely performs the office of conveying the blood to the lung, in order that it may be aerated or renovated in that organ. The capillary branches of the pulmonary artery, after ramifying through the lungs, at length unite together, and form four veins, two from each lung: they are well seen in *fig. 53*, and are marked *c, c; c, c*: these are called the *pulmonary veins*. The pulmonary veins transport the blood to the left heart, which consists of exactly the same number of parts as the right; namely, of these veins, which are represented in *fig. 47* by the letter *e*; of an auricle *f*; a ventricle *g*; and a large artery *h, h*. The *left auricle*, *f*, receives the blood now purified from the lungs; conveys it to the *left ventricle*, *g*, which propels it into the great artery, *h*, the latter being, as we now know, the aorta or the systemic artery. In this case, then, there are completed two perfect circles, by precisely corresponding instruments: one of these circles, the pulmonic, is through the lungs; the other, the aortic or systemic, is through the body: one of these circles commences in the capillary veins of the body, or the systemic veins,

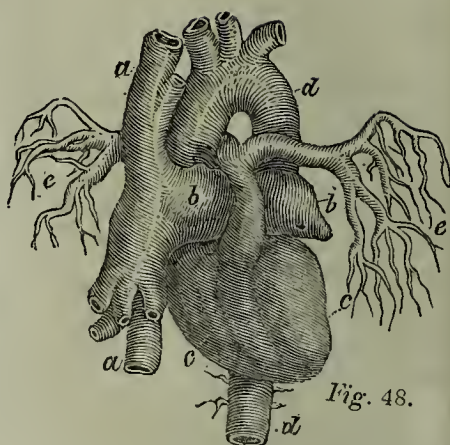
as constructed on this model, and for the sake of making the arrangement more intelligible, the two hearts are repre-

and terminates in the capillary branches of the pulmonary artery in the lungs: the other circle commences in the capillary branches of the pulmonary veins, and terminates in the capillary branches of the aorta; and since the capillary branches of the aorta open into and unite with the capillary branches of the systemic veins, it is obvious that this double course forms and completes one grand circle.

We have stated that, in order to render this description more intelligible, we have supposed these two hearts to be placed at some distance from each other. Had they been placed in opposite sides of the chest, it is clear that they might have carried on the circulation: but important advantages may result from the union; important advantages must result from their union, and, accordingly, they are united. The fibres of the two hearts intermix, and thus mutually strengthen each other; and both are enclosed in one and the same membranous capsule; namely, the pericardium: but though they are united, and acquire additional power by their union, yet the action of their different parts is precisely the same as they would have been had the right heart been placed in one part of the body, and the left in another. Thus the systemic and the pulmonic veins, the right and the left auricle, the right and the left ventricle, the pulmonic and the systemic arteries, correspond to each other in time and action, and perform their appropriate function in the most perfect and beautiful accord and harmony.

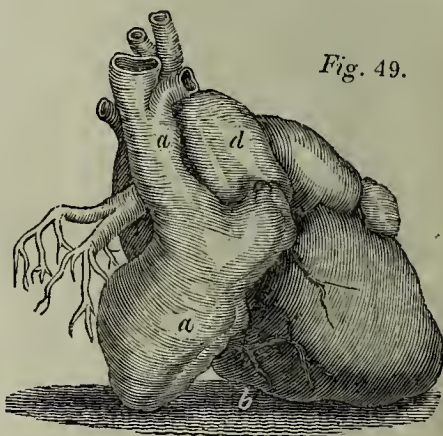
Fig. 48 represents the plan of a heart, constructed on this united and perfect model, and exhibits it such as it actually exists in the human subject. Thus, *a, a*, represent the two *venæ cavæ*; *b, b*, the right and left auricles; *c, c*, the right and left ventricles; *e, e*, the pulmonary artery, and *d, d*, the aorta. The pulmonary veins, being placed behind, can be seen only in a posterior view of the heart: they are represented in *fig. 53*, and marked by the letters, *cc, cc*.

In man, the apparatus of respiration consists of the lungs, and these occupy the cavity of the chest (*fig. 75*). The chest is divided into two portions, a right and a left portion, in each of which is placed one lung (*fig. 75 b, b*); hence there are two lungs, a right and a left, which have no communication with each other except by vessels. The heart is



Double Heart, united. *a a*, the two *venæ cavæ* (superior and inferior); *b b*, the two auricles (right and left); *c c*, the two ventricles (right and left); *e e*, the pulmonary artery, with its division into right and left branches; *d d*, the aorta.

placed in the left side of the chest, in contact with the left lung, towards its middle and lower part (*fig. 75, a*). Its direction (*fig. 49*) is oblique: its broad

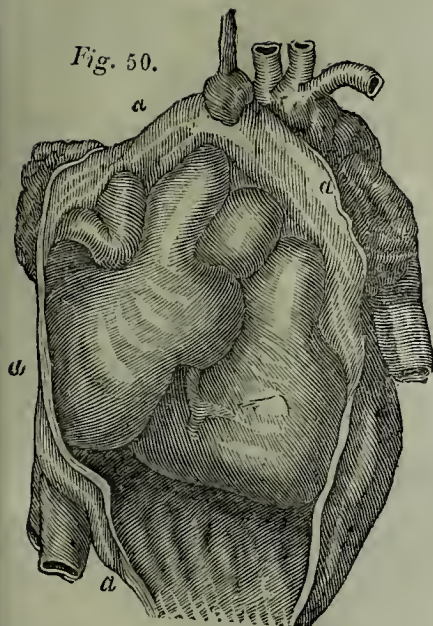


Position of the Heart, showing its oblique direction. *a a*, the *venæ cavæ*, distended; *b*, points to the situation of the basis of the heart; *c*, apex of the heart; *d*, the aorta.

part or basis is placed upwards, backwards, and to the right side: its apex is placed downwards, proceeds to the left, where its pulsation may be felt, corresponding to the fifth and sixth ribs.

The heart is held in its situation by a membranous bag which encloses it, and which is termed the pericardium. This bag is attached to the large vessels which spring from the heart a little above its basis (*fig. 50*): but no opening is formed

Fig. 50.



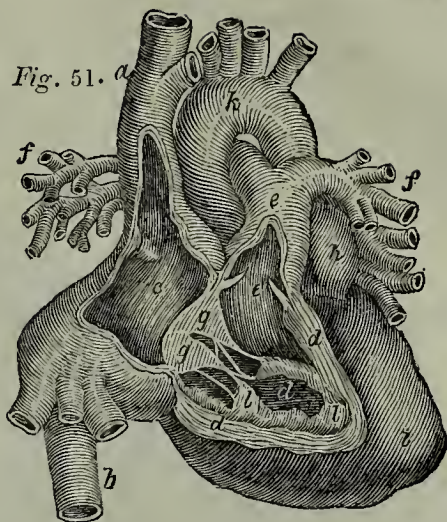
a a a, margin of the pericardium, which is here represented as cut open.

in the pericardium, for the outlet of the vessels. The vessels do not properly perforate the membrane; but the membrane is what anatomists call reflected upon them: that is, the inner layer of the pericardium is laid upon the external surface of the vessels, united closely with that surface, and insensibly lost upon it. This arrangement is extremely curious and beautiful: it constitutes the pericardium a closed bag, while, at the same time, it allows of the exit of these vessels.

The size of the pericardium is always in proportion to the magnitude of the heart. While this membranous bag fixes the organ firmly in its situation, it is as much larger than the heart as may be necessary to admit of its freest action; it sits loosely and easily about it, guarding its substance without confining its movements: it contains about a spoonful or two of limpid fluid, just sufficient to keep the surface of the heart in a state of suppleness and moisture. The action of the heart is essential to life, and must be incessant; and, therefore, the most extreme care is taken to afford it a free space to act in, and to guard that space from invasion.

By looking at *fig. 51*, it will be seen that the right auricle (*fig. 51, c*) is situated at the basis of the right ventricle: it is here partly opened: at its

Fig. 51.



Right side of the heart, or pulmonic portion. *a*, superior vena cava; *b*, inferior vena cava; *c*, right auricle, opened; *g g*, the valve occupying the opening leading from the right auricle into *d*, the right ventricle; *d d*, the cut edges of the right ventricle, showing the thickness of its muscular wall; *e e*, the pulmonary artery, arising from the right auricle, and dividing into two large branches *f, f*, which go to the right and left lung.

upper and back part is the opening of the *vena cava superior*, *a*, which, as we have seen, returns the blood from the head, neck, and upper part of the body: opposite to it is the opening of the *vena cava inferior*, *b*, which returns the blood from all the lower parts of the body.

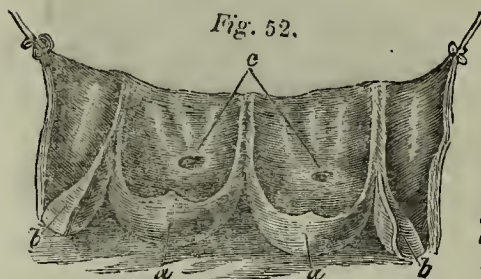
From the right auricle a large opening leads into the right ventricle, termed the *auricular orifice of the ventricle*: its situation is marked, and is occupied by the valve, *g, g*.

The right ventricle is much more thick and muscular than the auricle; there is spread over its internal surface an irregular net-work of fibres, some of which are marked by the letters *l, l, l*. Many of these fibres are fixed by one extremity to the sides of the ventricle, while the others terminate in tendinous threads which are attached to the membrane forming the valve *g, g*, placed around the auricular orifice: to this membranous valve attention will be drawn immediately.

From the upper and left side of the right ventricle springs the pulmonic artery *e, e*, at the entrance of which are placed three membranes of a crescent or semilunar shape, termed the three semilunar valves: their situation is marked by the letter *e*, and their form is well

seen in *fig. 52*, which shows two of the semilunar valves of the aorta entire.

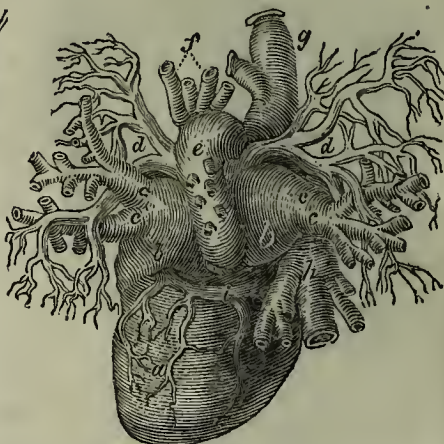
The structure of the left side of the heart is so similar to that of the right, and the action resulting from that structure so analogous, that a few words only will be necessary to complete the description of the circulatory apparatus.



a, a, two of the semilunar valves of the aorta; *b, b*, the third divided; *c*, the coronary arteries.

The left auricle, the external figure of which is best seen in a posterior view of it, as in *fig. 53*, *b, b*, is furnished in the interior with muscular fasciculi, similar to those of the right. In its upper and back part (*fig. 54, f*) are found four openings, which are the mouths of four veins, two from the right, and two

Fig. 53.



Represents a posterior view of the Heart. *a*, the left ventricle; *b b*, the left auricle; *c c c c*, the four pulmonary veins; *d d*, the two great branches of the pulmonary artery; *e*, the aorta; *g*, the superior vena cava; *h*, the inferior vena cava; *f*, branches given off from the aorta.

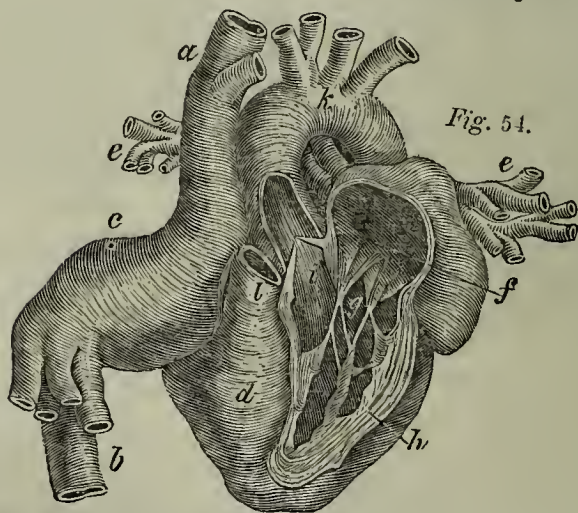


Fig. 54.

a, superior vena cava; *b*, inferior vena cava; *c*, right auricle; *d*, right ventricle; *i*, the trunk of the pulmonary artery cut off and removed, in order that the other parts shown by the figure may be seen distinctly; *e e*, point to the direction of its right and left branches; *f*, left auricle, pointing to the opening of the four pulmonary veins, two from the right and two from the left lung; *g*, the valve placed at the opening between the left auricle and the left ventricle, connected by tendinous cords with the fleshy columns which are seen arising from the wall of the ventricle; *h*, thickness of the wall of the ventricle; *i*, commencement of the aorta, springing from the left ventricle; *k*, the arch of the aorta, with the great branches given off from it.

from the left lung, termed, therefore, pulmonic: these veins are seen in *fig. 53*, and are marked *c, c, c, c*.

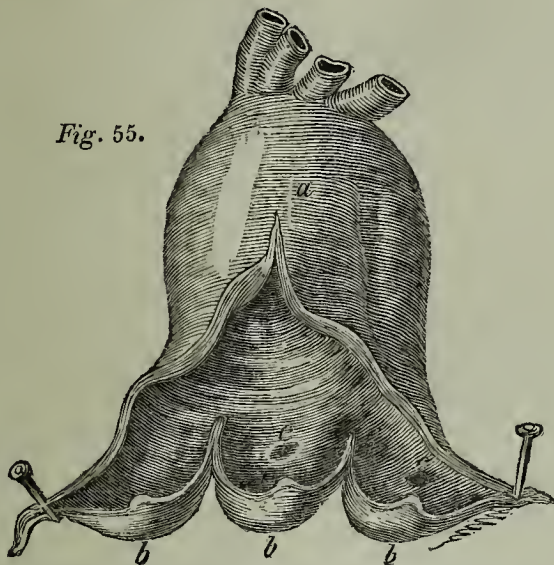
Between the left auricle and the left ventricle a valve is placed, corresponding to the valve on the right side (*fig.*

54, *g.*) The parietes of the left ventricle are nearly as thick again as those of the right (*fig. 54, h.*) From its upper and back part springs the great artery which conveys the blood to every part of the body, the aorta (*fig. 54, k.*) Around the commencement of the aorta are

placed three semilunar valves (*fig. 55, b, b, b*), similar to those at the mouth of the pulmonary artery.

The heart itself is composed of four distinct tissues: first, of a layer of the pericardium, which, being reflected, forms its external surface; secondly, of

Fig. 55.



Represents the aorta slit open towards its arch, *a*, in order to show entire the three semilunar valves, *b b b*, placed at its mouth; *c c*, the coronary arteries.

a fine transparent membrane, which lines the whole of its internal surface; thirdly, of muscular substance, which is included between these two membranes; and, fourthly, of cellular tissue, which surrounds and invests the muscular fibres; and which, on account of the elasticity which, it has already been shown, is the distinctive property of this tissue, is absolutely essential to the action of the organ. Though the cellular tissue, as it is mixed up with the muscular fibre of the heart, is extremely delicate, yet it endows the heart with such an eminent degree of elasticity, that if a portion of the ventricle be cut and stretched, it regains its original bulk and figure the instant the distending power is removed. The necessity and the beauty of this structure will abundantly appear when we treat of the heart's action.

Such is the structure of the apparatus for the circulation*; but it is still neces-

sary to add a few words relative to the structure and distribution of the vessels which carry out and return the blood, before the function can be understood.

The vessels which are essential to the apparatus of the circulation, consist of three distinct orders, namely,—1. the arteries; 2. the veins; and 3. the lymphatics. The different function performed by the arteries and the veins has already been stated; the lymphatics, which may be considered as appendages to the veins, although they do not convey blood, but chyle and lymph, are an essential part of the circulating system, because they transport to the former vessels the fluids which supply them, and they communicate directly with both orders, obviously with the veins, and so readily even with the arteries, that injections will pass from the arteries into the lymphatics.

Arteries and veins possess three coats, the lymphatics only two. Of these the external is called the cellular coat. It consists of small whitish fibres which are

* Those who wish for a more detailed account of the structure of this apparatus than it was possible to give in this place, are referred to the valuable work of Messrs. John and Charles Bell, on the Anatomy and Physiology of the Human Body, from

which several of the figures illustrating this Treatise have been taken, viz. *figs. 47, 48, 49, 50, &c.*

very dense and tough, and which interlace together in every direction. It is proportionably thicker in the larger than in the smaller arteries, and it gives to the vessel its chief strength. Its most important property is its elasticity, with which it is endowed in a very high degree. The second is termed the middle or the fibrous coat. It consists of fibres of a yellowish colour, which pass in a circular direction around the calibre of the artery, forming not complete circles, but segments, which, uniting, produce rings. These fibres are disposed in several successive layers, which can be readily peeled off one after the other, and which form altogether a pretty thick tunic. It is thicker in the small branches than in the large trunks, the reverse of what is found in the cellular coat. While it is firm and elastic it is extremely brittle; but by far its most important property is its contractility, with which vital property it is eminently endowed, and the exercise of which is essential to the function of the vessel. Since in man and the higher animals the property of contractility is confined to the muscular fibre, this fibrous coat has been supposed to be of a muscular nature; but it is so different in its aspect from the muscular fibre, that its muscularity has been vehemently denied by some of the most distinguished anatomists and physiologists: it may be, however, and it probably is, a modification of the muscular fibre. The third or internal coat consists of thin, dense, whitish, and almost transparent fibres, which are smooth and polished in their aspect; and the whole surface of the tunic is moistened with a thin and somewhat unctuous fluid. In many parts the membrane is formed into folds of a semilunar shape, which are termed valves, and which are disposed in such a manner, that they allow a free passage to the blood in the course required by the circulation, but effectually prevent the retrograde direction of the current. This tunic, though thin, is so firm and strong, that after the other coats have been entirely removed in a living animal, it is capable of resisting the impetus of the blood, and of preventing the dilatation of the artery; it is smooth and polished, to afford as little friction as possible to the blood, and firm and strong, to prevent its escape.

All these vessels are themselves abundantly supplied with vessels termed the *vasa vasorum*, by which they are

nourished, and which are essential to their life and action. Each individual part of an artery is furnished with its own appropriate vessels, and when it is necessary in surgical operations to tie the trunk of an artery, it is found that the utmost care must be taken to disturb it as little as possible, exposing just as much of it as is absolutely required for the application of the ligature; for if it be detached from its situation to any extent, its natural vessels are ruptured, and so its supply of nourishment is cut off, whence it becomes diseased, and ultimately dies, or in surgical language it ulcerates and sloughs, and the consequence often is fatal hæmorrhage.

In like manner all these vessels are abundantly supplied with nerves, which, in the artery, appear to be distributed principally to the fibrous coat, and to endow it with a peculiar sensibility—a sensibility which causes it to receive a peculiar impression on the contact of the blood—an impression which excites it to contraction, the blood thus forming its appropriate stimulus.

From what has been said of the vascular system, it is evident that the vessels which compose it are highly important organs; that no injury can be inflicted on them without producing serious mischief, and that any considerable violence applied to them must necessarily be attended with a fatal result. On this account the greatest possible care has been taken to protect them, by placing them in situations in which external force can scarcely reach them. These great trunks are uniformly situated in the cavities of the body, or are embedded deep in the substance of the limbs: they pursue their course in the neighbourhood of the bones, and under their shelter; often in grooves excavated in the bones, on purpose to receive and secure them. Whenever they approach the surface, they divide into small branches, and this division goes on diminishing the calibre of the vessels, until when actually at the surface they are exceedingly minute. A wound in an artery being much more dangerous than a wound in a vein, on account of the greater impetus with which the blood is propelled through the former, the artery always lies deeper than the vein, and is more embedded in soft and elastic substances, and more concealed in channels formed in the bones, or protected by stout parapets thrown up on each side of it.

As it is indispensable to the maintenance of health, and often to the preservation of life, that every organ should receive a due supply of blood, two expedients are adopted to guard against an interruption to the circulation in any part. In the first place, every organ receives a supply from more than one source, and by more than one arterial trunk; all the important organs form several: the brain, for example, receives four exceedingly large trunks from four distinct and independent sources; and in the second place, all the branches unite together so intimately, that if the blood find the slightest check in one branch, it instantly finds an open channel in another. Perhaps in the whole compass of animated nature no sight is more beautiful than the inspection of the transparent part of a living animal by means of a microscope: the intersection and mingling of the different vascular branches, through all of which the particles of the blood find the readiest conceivable access, forms not only a most curious but most wonderful object. This union, or, as anatomists term it, inosculation of vessels, is capable of being increased to an astonishing extent in particular states of the system. If, from any cause, a large branch of an artery be obstructed, the other branches which it gives off are capable of enlarging sufficiently to carry on the circulation without impediment; and even if the main trunk be obliterated, the collateral branches will perform its function so perfectly as to prevent the system from sustaining any material injury. Guided by the knowledge of this principle, modern surgeons daily undertake operations, the idea of which would have filled with terror the surgeons of former days. Trunks of arteries are taken up of amazing size, and in situations where one would have thought it must be certain death for the needle of the surgeon to penetrate. If the reader will cast his eye on any map of the arteries, he will be struck with the force of this observation, when it is stated that these splendid achievements of modern surgery were accomplished in the following order:—First, the operator ventured to take up the femoral artery; then the external iliac; then the subclavian artery below the clavicle; then the common carotid; then the subclavian artery above the clavicle; then the internal iliac; then the arteria innominata; and lastly, even the abdominal aorta itself. By

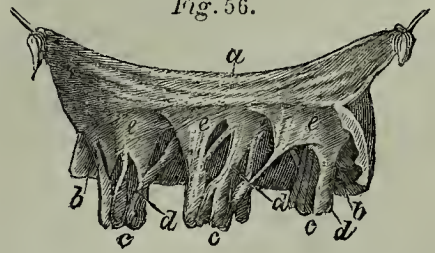
these difficult and stupendous operations, diseases which appear to be far beyond the reach of all human aid, and which without aid proceed with a sure and rapid pace to a fatal termination, are arrested.

Course of the Blood in Man.

The blood is returned from all parts of the body into the right auricle by the superior and inferior vena cava. From the right auricle it is propelled into the right ventricle. From the right ventricle it is conveyed by the pulmonic artery into the lungs. From the lungs it is returned by the four pulmonic veins into the left auricle. From the left auricle it is propelled into the left ventricle, and thence it is conveyed to every part of the body by means of the aorta.

But in pursuing this course there is an obvious difficulty. When the blood is propelled onwards by the contraction of the heart, why does not the force that moves it cause it to flow backwards as well as forwards? When, for example, the right ventricle contracts, why is not the blood propelled backwards into the right auricle as well as forwards into the pulmonary artery? When the ventricle contracts, its necessary tendency must be not only to force the blood into the artery which the course of the circulation requires should receive it, but also into the auricle from which it has been just transmitted. There is no other possible means of obviating this fatal impediment to the circulation than that of placing a valve between the artery and vein. Accordingly a valve is placed there (*fig. 55, b, b, b*). The action of the valve is as follows:—As long as the blood proceeds in its proper course, it presses the valve close to the side of

Fig. 56.



Represents the valve placed between the right auricle and the right ventricle, the auricle and ventricle being supposed to be cut open, and the valve hanging in three great divisions; *a*, part of the inside of the auricle; *b*, part of the inside of the ventricle; *c c c*, the columns carneae; *d d*, the cordæ tendineæ; *e e e*, the three great divisions of the valve.

the heart; and, consequently, prevents the valve from occasioning any impediment to the circulation. On the contrary, the moment the blood begins to flow backwards into the ventricle, it insinuates itself between the wall of the ventricle and the valve; forces up the valve from the side of the ventricle; causes it to occupy the passage between the ventricle and the auricle; and thus completely shuts up the channel. How effectually it does this, is well seen in *fig. 57, a*, which represents the figure

Fig. 57.



Represents the figure which the three semilunar valves, placed at the mouth of the aorta, assume when distended by the reflux blood.

assumed by the three semilunar valves, placed around the mouth of the aorta, when they become distended by the reflux blood. As is clearly seen in this figure, they so completely shut up the passage that not a particle of fluid can pass backwards into the ventricle.

There is a further contrivance adopted, and one which the mind cannot contemplate without admiration, in order to render the action of the valve, placed between the auricle and ventricle, perfect. Were the membrane, which is placed in this situation, loose, it is obvious that the reflux blood would carry it back into the auricle, and thus effectually prevent its action as a valve. But it has been stated that the fleshy columns, which are placed in the wall of the ventricle, (*fig. 56, c, c, c*), give off numerous tendinous threads, *d, d*, which are attached by one extremity to these fleshy columns, and by the other to the

loose edge of the valve, *e, e, e*. These tendinous threads, like so many strings, tie down the valve to its proper situation; and being thus secured, the membrane is not only prevented from being carried by the impetus of the reflux blood too far into the auricle, but that very impetus is the means of giving it the distension and figure that are required. But the perfection and beauty of the mechanism do not stop even here. It has been stated that each of these fleshy columns may be considered as a distinct muscle: each is endowed with the peculiar property of the muscular fibre, that of contractility: each is excited to contraction by the contact of the blood just as the ventricle itself: each, therefore, by contraction shortens all the tendinous threads attached to it just at the moment that these strings require to be tightened; and they further tighten them in the precise proportion required: for the distension of the membrane by the reflux blood stretches these tendinous threads, and the stretching of the tendinous threads stretches the fleshy columns: the fleshy columns are thus still further irritated, excited, stimulated: the consequence of this increased excitation is proportionally increased contraction, and the ultimate result, increased security that the valve will be held in the precise position that is required, with exactly the degree of strength that is wanted. Thus there is accomplished here the construction of a valve, which is not only most perfect in itself, but which is endued with a property to which no other mechanism affords any parallel, a valve capable of generating a power that enables it to act with additional force whenever additional force is requisite. Among the countless instances of wise and beneficent adjustment familiar to the student of nature, there is commonly some one upon which his mind rests with peculiar satisfaction; some one to which it finds itself constantly recurring as affording *the* proof, which cannot be resisted, of the operation of an intelligence that has foreseen and planned an end, and provided for its accomplishment by the most perfect means: and surely there is nothing more worthy to become one such resting-place to the philosophical mind than the structure and action of the valves of the heart.

Valves are placed between the right auricle and ventricle; at the mouth of the pulmonary artery, between the left

auricle and ventricle, and at the mouth of the aorta.

Quantity of Circulating Blood in Man.

Each cavity of the heart may contain from two to three ounces of blood. The heart contracts four thousand times in one hour: therefore, there passes through the heart, every hour, eight thousand ounces, or seven hundred pounds of blood. The whole mass of blood in an adult man is about twenty-five or thirty pounds, so that a quantity of blood equal to the whole mass passes through the heart twenty-eight times in an hour, which is about once every two minutes. What an affair must this be in very large animals! It has been said, and with truth, that the aorta of a whale is larger in the bore than the main pipe of the waterworks at London Bridge, and that the water roaring in its passage through the pipe is inferior in impetus and velocity to the blood gushing from a whale's heart. Dr. Hunter, in his account of the dissection of a whale, states that the aorta measured a foot in diameter, and that ten or fifteen gallons of blood are thrown out of the heart at a stroke with an immense velocity, through a tube of a foot diameter.

It has been well observed, that we cannot be sufficiently grateful that all our vital motions are involuntary, and independent of our care. We should have enough to do had we to keep our hearts beating and our stomachs at work. Did these things depend, not to say upon our effort, but even upon our bidding, upon our care and attention, they would leave us leisure for nothing else. Constantly must we have been upon the watch, and constantly in fear: night and day our thoughts must have been devoted to this one object; for the cessation of the action, even for a few seconds, would be fatal: such a constitution would have been incompatible with repose.

The wisdom of the Creator, says a distinguished anatomist, is in nothing seen more gloriously than in the heart. And how well does it perform its office! An anatomist who understood its structure might say beforehand that it would play; but from the complexity of its mechanism and the delicacy of many of its parts, he must be apprehensive that it would always be liable to derangement, and that it would soon work itself out. Yet does this wonderful machine go on, night and

day for eighty years together, at the rate of a hundred thousand strokes every twenty-four hours, having at every stroke a 'great resistance to overcome, and it continues this action for this length of time' without disorder, and without weariness.

That it should continue this action for this length of time without disorder is wonderful; that it should be capable of continuing it without weariness is still more astonishing. Never, for a single moment night or day, does it intermit its labour, neither through our waking nor our sleeping hours. On it goes, without intermission, at the rate of a hundred thousand strokes every twenty-four hours, yet it never feels fatigued, it never seems exhausted. Rest would have been incompatible with its functions. While it slept the whole machinery must have stopped, and the animal inevitably perish. It was necessary that it should be made capable of working for ever without the cessation of a moment, without the least degree of weariness. It is so made, and the power of the Creator in so constructing it can in nothing be exceeded but his wisdom.

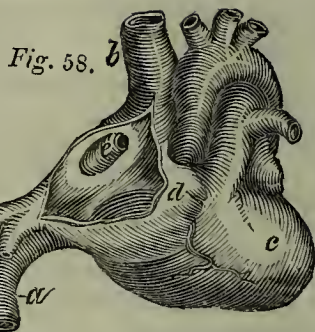
Proofs of the Circulation.

That the course of the blood is such as has now been described, is demonstrated, first, by the structure and disposition of the valves of the heart. The valves placed at the two auricular apertures are so situated as to prevent the contents of the ventricles from returning into the auricles, while the contents of the auricles are allowed a free passage into the ventricles: at the same time the valves placed at the mouths of the pulmonary artery and the aorta allow the contents of the ventricles to pass into the arteries, but prevent the contents of the arteries from returning into the ventricles. And the countless valves which crowd the venous system are all so arranged as to permit and assist the passage of the blood from the arteries through the veins, while they effectually resist its return from the veins through the arteries. Secondly, it is still more certainly proved by the effect of ligatures. When a ligature is thrown around a vein the blood accumulates in that portion of it which is most distant from the heart, while the portion which lies between the ligature and the heart continues to carry forward its contents, and soon becomes empty. When, on the contrary, an artery is subjected to a

similar experiment the reverse occurs. That portion of the artery which lies between the ligature and the heart becomes full and swollen, while the other parts become flaccid, proving clearly that the contents of these two vessels move in opposite directions, and that the natural current of the blood is from the heart to the artery, from the artery to the vein, and from the vein to the heart. Finally if the web of a frog's foot be examined through a microscope, the blood may be seen pursuing the course now described. The minute particles of which it consists are observed to flow in innumerable streams, the streams constantly intersecting each other, and occupying every point of space within the view. It is a sight which no man who has once seen can ever forget; and he who has not seen it, has not beheld one of the most curious, and wonderful, and beautiful objects which animated nature presents.

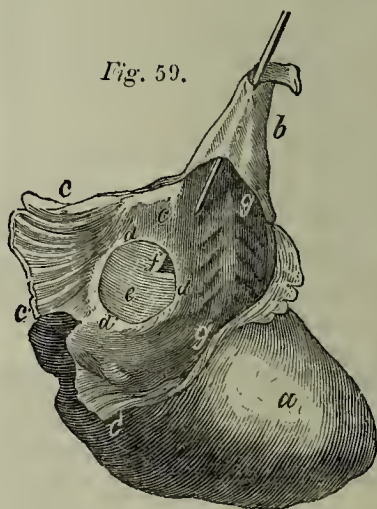
Course of the Blood in the Fœtus.

The preceding account relates entirely to the course of the circulation in the adult: it is a highly curious and interesting fact, that, in the unborn child, it is materially different. Since respiration is not only incompatible with foetal life, but since the blood of the fœtus, or unborn child, comes to it sufficiently purified from the system of its mother, its lungs neither can, nor are required, to exert any influence upon its blood. To circulate all this fluid through these organs, while in this quiescent state, would only complicate the function, without rendering it more perfect. So much only is, therefore, sent to them as is necessary for their nourishment, and the rest is, by a beautiful but simple contrivance, passed onward to the system from the right to the left side of the heart, with the least possible loss of purity, or waste of time. To effect this, a heart, which is actually double, and ultimately intended for a double circulation, is converted for a time into a single organ; and, strange as the assertion may at first appear, man, when viewed in different periods of his existence, may be regarded as both a cold and a hot blooded animal. The right auricle is made to communicate freely with the left, by means of an oval aperture, placed in the centre of the partition which divides them (*fig. 58*); and the blood of the right ventricle is made to mingle directly with that of the left, by a com-

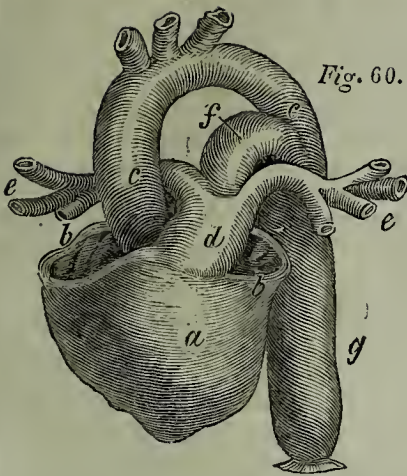


Represents the heart of the fœtus; *a*, the inferior vena cava; *b*, the superior vena cava; *d*, the margin of the right auricle which is here seen opened; *e*, the foramen ovale, or the oval aperture, situated in the partition which separates the right from the left auricle.

municating vessel, termed the *ductus arteriosus*, or the arterial duct, which is placed between the pulmonary artery and the aorta (*fig. 60*.) The oval hole is guarded by a valve (*fig. 59, e*), which, being placed within the left auricle, allows the passage of blood from the right to the left auricle only; and runs so obliquely between the pulmonary artery and aorta that, while the contents of the former vessel are encouraged into the latter, those of the latter vessel can never retrograde into the former. By means of the communicating aperture, a great portion of the blood, which enters the right, is



Represents the heart of the fœtus, with all the parts cut away excepting the ventricles and the partition between the auricles; *a*, the ventricles; *b*, the vena cava, with a blow-pipe in it; *c*, the wall or partition between the auricles; *g*, the muscoli pectinati, or the muscular fibres of the auricle; *d, d, d*, margin of the foramen ovale; *e*, the valve of the foramen ovale; *f*, a small opening always seen at the upper part of the valve.



Sketch of a preparation made to show the ductus arteriosus; *a*, the ventricles; *b*, the place from which the two auricles are cut away, in order that they may be seen distinctly; *d*, the pulmonary artery, arising from the right ventricle; *e, e*, the right and left branches of the pulmonary artery going to the right and left lungs; *f*, the ductus arteriosus, or the arterial duct passing directly from the pulmonary artery to *c, c*, the aorta; *g*, the aorta increased in size by the addition of the arterial duct.

passed immediately into the left auricle, in place of being previously journeyed through the right ventricle, pulmonary artery, and lungs; and by means of the communicating vessel (the arterial duct) a great portion of the blood, which had not previously passed through the oval hole into the left auricle, but through the auricular foramen into the right ventricle, is sent directly to the arch of the aorta, to meet and mingle with the rising current as it issues from the left side of the heart. The right and left auricles are thus, as it were, thrown into one common cavity, by the intervention of the oval hole; by means of the arterial duct, the right and left ventricles unite in propelling at the same moment into the aorta the blood which they contain; and the right auricle and ventricle are made subservient to the left auricle and ventricle, instead of being supernumerary apartments in a double heart, conducting a single circulation.

The peculiarities of the foetal circulation, it is hoped, may now be understood. The blood, which is sent from the placenta to the child, arrives at the right side of the heart, and is admitted into the right auricle. When the auricle becomes full, it contracts, part of the blood which it contains enters the right ventricle by the ordinary way, and part passes through the oval hole between the right and left auricles into the left side of the heart.

That portion which passed immediately into the left side of the heart through the oval hole is sent out directly by the left ventricle into the aorta, to be distributed throughout the body; and that portion which entered the right ventricle is sent on towards the lungs, through the pulmonary artery, but, by entering the connecting branch which runs between this artery and the aorta (the arterial duct), the greater part of this second portion likewise escapes into the aorta, thus leaving only a fraction of the blood which had at first entered the right auricle to continue its ordinary journey to the lungs. After the blood has reached the aorta, it follows the usual route in its course along the body, but, in place of immediately returning to the right auricle, as in the circulation of the adult, it passes out of the body through the navel of the child by two vessels in the navel string, or umbilical cord, goes back to the placenta, and then returns by a single vein along the cord to the foetal heart, renovated and prepared for another circulation.

As soon as the child is born, however, this modified circulation ceases. At this period two important changes occur—the connexion which had subsisted between the maternal and the foetal systems is dissolved, and the lungs of the child begin to act. In virtue of the first change, no more blood can be received from the mother: in consequence of the second, the blood of the child must commence a double circulation. The first change will occasion less blood to be received into the right auricle, and the admission of more blood into the left will result from the second change. The relations of the foetal circulation are thus reversed, and the very causes which formerly gave rise to its peculiarities are now employed for their removal. During the foetal circulation, the communicating aperture between the auricles continued open, because the contents of the right auricle exceeding in quantity those of the left, the momentum of the circulation was from the right auricle to the left; and the communicating vessel which ran between the pulmonary artery and aorta likewise remained pervious, because circulation through the lungs, in their collapsed state, was difficult. But at birth, the auricular aperture closes, because the supply of the right auricle being no greater, and at first less than that of the left, the determination of the circulation

is from the left to the right auricle, and, therefore, the valve of this aperture, which lies in the left auricle, is so compressed against its walls during every contraction, that adhesion between the margins of the valve and the aperture ultimately takes place, and the arterial duct, or vessel of intercourse between the pulmonary artery and aorta, also closes, because the expanded state of the lungs encourages the passage of the blood from the right to the left cavities of the heart.

Circumstances purely physical are thus found to account for the very different states of this function in the *foetus* and in the adult. The connexion of the former with its mother's system not only renders a single circulation necessary, but leads to the very apparatus for its establishment; and the *aërial* medium by which the latter is surrounded not only requires a double circulation, but furnishes important facilities towards its execution. The auricular aperture and communicating vessel being now closed, the heart, which before was only anatomically double, is now made functionally so; and the blood, which was before limited to a single circulation, is now made to undertake a second journey. There is no parallel to the perfection of this contrivance, but the simplicity of the mechanism by which the objects required are secured; and that mechanism affords one of the most beautiful illustrations, at once of skilful adaptation and of prospective arrangement.

Powers by which the Blood circulates.

Such is the machinery by which the blood circulates and the course in which it flows. It is an interesting and somewhat difficult point to determine what is the agency by which this machinery is wrought, or what are the powers which are brought to bear upon it to put it in motion, and to keep that motion up without ceasing, without weariness, without thought, for the most part without even consciousness, during every moment of our life, through our sleeping and our waking hours.

Some have imagined that as the blood is a living fluid, it cannot be considered passive during its circulation; but that, by putting into action its own vitality, it materially contributes to its own movement. Others have studied the science of hydraulics with the hope of discovering the circulating powers, and, forget-

ting that man is a living being supported by vital functions, the sanguiferous system has been regarded as a clever illustration of mechanical principles working upon dead matter. It is unnecessary to say how far both doctrines are distant from the truth; and it is quite certain that many of the phenomena of this function must have appeared impenetrably obscure to the advocates of either. It was the doctrine of Harvey, that the only organ which conducted the circulation was the heart; and this opinion has been warmly advocated by many subsequent physiologists. But it has been already shewn that in many of the inferior classes of animals, a circulation may exist without a heart; its introduction being only necessary when organization became voluminous, and structure complex. In insects there is no central organ. In fishes, the *branchiæ*, or gills, intervene between the aorta and heart; so that the blood, after it leaves the *branchiæ*, must move by some agency independent of the heart; and in the human species, cases have been met with in which a circulation must have obtained for a considerable period without any central organ. A *foetus*, fifteen inches high, has been described by Mr. Brodie as not having had a heart; and the *mola*, or imperfect child, frequently attains a very considerable size without the advantage of such an organ.

It is obvious, therefore, that however essential the heart may be to the circulation of the blood in many classes of animals, certain forms of this function may proceed without it; and it will soon be shown that even in man several other important agents are employed.

Action of the Heart on the Circulation.

When the chest of a living animal is opened and the heart exposed, the following appearances are witnessed. The right auricle is seen to contract while the right ventricle dilates; and when the right ventricle dilates, the pulmonary artery contracts. The same alternations of action take place in the left side of the heart. As the left auricle contracts, the left ventricle dilates; and as the left ventricle dilates, the aorta contracts. The two auricles, consequently, dilate together, the two ventricles contract together, the pulmonary artery and aorta are filled at the same time, and the *venæ cavæ* and pulmonary veins pour their contents at the same moment into the auricles. The

harmony, with which these different actions proceed, is as beautiful as the necessity of such harmony is obvious. Did the ventricles persevere in contracting after their contents had been expelled, the auricles would be unable to fill them; and did the auricles forget to contract when full, the ventricles would continue empty. As it is arranged, however, the ventricle is empty when the auricle is full, and contraction commences the moment relaxation terminates; so that as soon as the auricle is prepared to fill the ventricle, the ventricle is prepared to relieve the auricle; and the ventricle is no sooner ready to propel its contents into the artery, than the artery is also ready to receive them. This systematic alternation of giving and receiving is continued, until the blood which entered the right auricle leaves the left ventricle.

Many ingenious conjectures have been hazarded respecting the cause of this curious succession of alternate actions. The ancients believed that there dwelt an inherent pulsific virtue in the heart, which enabled it to contract and dilate alternately. Some conceived that the auricles and ventricles were antagonist muscles, and that the same cause, which operated upon the auricles as a stimulus to contraction, acted at the same time as a sedative upon the ventricles in causing relaxation. Some ascribed to an effervescence between the acid and alkaline principles of the blood, what others traced to the *archeus, anima*, or intelligent agent, which was supposed to superintend the vital functions. Haller explained all upon an unknown, yet acknowledged principle, which he called irritability; and Le Gallois has endeavoured to prove that the heart depends upon the spinal marrow for all its varieties of motive power. By introducing a metallic rod into the vertebral canal, he found that the action of the heart weakened as he broke down the spinal cord, and that when it was completely destroyed, this organ had lost all power of supporting the circulation. But similar experiments have subsequently proved that the spinal marrow may thus be broken down throughout its whole extent, and yet the heart continue its action for a considerable time. It is also certain that the heart, when separated from the body, may be stimulated to contraction by being immersed in warm water, or pricked with a sharp-pointed instrument; and likewise that

in an animal, which has recently expired, its action may be for a time restored, by supporting an artificial respiration. Such facts, and they might be variously multiplied, are well known, and the inference to which they tend is obvious; yet it must be admitted that there are phenomena of an opposite nature strongly indicative of the influence of the nervous system upon the heart. The blood-vessels of a palsied limb begin to diminish shortly after the attack; its supply of blood lessens as its power sinks; emaciation keeps pace with impaired sensibility, and mortification is not unfrequently the consequence of a paralyzed circulation. And as in diseases of the nervous system, the functions of the heart and arteries are more, and sooner disturbed than perhaps any other; so even in health there is no organ so much under the power of the mind as the heart: fear depresses its activity, and joy excites it; it is, in short, so much the victim of mental emotion, that it is popularly called the seat of passion; and to speak in the language of the heart is considered as characteristic of sincerity, as it is of grief, to say that the heart is broken. The only legitimate inference which can be drawn from such conflicting premises is that, while the heart is not perhaps as immediately dependent upon the brain, as the brain is upon the heart, both are necessary for the efficient action of either.

The heart is a hollow muscle, possessing both elastic and contractile powers. Its contractility depends on the muscular fibres of which it is principally composed: its elasticity on the cellular tissue which, as we have seen, is mixed up with the muscular. Its elasticity is inferior to its contractility; but its elasticity is indispensable. When the heart contracts, its muscular fibres have not only to expel the blood, but to overcome the elasticity which would prevent contraction; and when it dilates, the muscular fibres relax, and allow its elasticity to operate. The one is a vital, the other a mechanical agent. Power is created by the action of contractility, but elasticity merely restores a part to its primitive condition, when the constraining force has ceased to operate.

The cause of the heart's contraction is the entrance of blood into its cavities; the cause of the heart's dilatation is the action of its elasticity when its contractility has ceased. In this manner may

be explained what have been called the *systole* or contraction, and the *diastole* or dilatation of this organ. The elastic power facilitates the reception of blood into the heart; the contractile power effects its departure from it. The elastic power opens the auricle, the contractile power closes the ventricle. When the contents of the auricle have been expelled, as soon as the contractile power has so relaxed as to give the elastic power the superiority, dilatation commences, and proceeds until the walls of the auricle have resumed their natural state. A vacuum is, therefore, formed within the auricle, and the blood, which is urged forward to the heart along the veins, is invited by this vacuum into the auricle. Elasticity and contractility are, then, the two great powers by which the heart acts.

Supposing that the quantity of blood taken into the heart during each dilatation be two ounces and a half, that the heart contract seventy-five times in a minute, and that thirty pounds represent the quantity of blood circulating in the body of a moderately sized man, the whole mass of blood will pass through the heart twenty-three times every hour, and an entire circulation will be performed every three minutes. The time spent during one circulation may thus be easily ascertained; but it is more difficult to discover how far the action of the heart extends along the arteries, and at what rate the blood travels in different stages of its journey.

From experiments carefully made and frequently repeated, it is believed that the left ventricle projects its blood into the aorta with a velocity equal to twenty-one feet in the minute. By inserting a glass tube into a large artery, Hales found that the blood rose eight feet and three inches above the level of the left ventricle during every contraction of the heart, and hence infers, that the blood would rise seven feet and a half high in a similar tube fixed into the carotid artery of a man. "The internal area of the left ventricle of the heart (he observes) is equal to fifteen square inches; these multiplied into seven feet and a half give 1350 cubic inches of blood, which press upon that ventricle when first it begins to contract; a weight equal to 51—5 pounds."

It is certain, however, that if the velocity with which the blood leaves the left ventricle, supposing it to be equal to twenty-one feet in a minute, were

maintained throughout its whole course, three minutes could not be spent in a single circulation. Several of the reasons why this cannot be the case will soon appear, and it is not unlikely that the power of the heart has been overestimated. Borelli conceived that it was equal to 180,000 pounds; Senac reduced it to 4.00; and Keil diminishes it to the insignificant fraction of eight ounces. The amazing discrepancy, which such calculations betray, is a tolerable proof that little importance is to be attached to any of them; and it was to be expected that they, who looked to the action of the heart alone for the agency by which the blood circulates, would be tempted, for the sake of system, to ascribe to it an undue influence.

Action of the Arteries on the Circulation.

By such physiologists the arteries were contemplated as lifeless and passive tubes, useful only because connected with a living and acting organ. But it has been already stated, that a circulation may be conducted even in the human system without a heart; that in insects there is no such organ, and that in fishes two-thirds of the blood with which they are supplied are circulated by means of vessels only. Since, however, this function may exist without a heart, while an artery is always necessary, it is obviously absurd to attempt to explain the circulation upon mere hydraulic principles, or to ascribe to the heart the entire credit of its performance. In living beings the agency of machinery must ever be studied in connexion with the influence of life. Each is equally necessary to the establishment of function. No physical process can be conducted by life without machinery, and machinery without life cannot execute any physiological function. Were arteries lifeless tubes, attached to the heart for the sake of convenience, as leather pipes in a water-engine are connected with the piston, the science of hydraulics might be legitimately applied to the action of these vessels, and to estimate the force of the heart's agency would be to measure the strength of the circulating powers.

This plan has been attempted, but it has failed, and the heart has been invested with a degree of force quite incompatible with the structure of such an organ, in order to account for phe-

nomena which were not to be explained upon so limited a system. If the capillary extremity of an artery be placed in a microscope, it will be seen to contract and dilate as regularly as the heart. If the aorta be tied as it issues from the heart, the blood which it contains beyond the ligature will be urged forward as usual into the veins. And if the heart be wholly removed from the body, the circulation may be observed to go on for some time afterward in the capillary vessels. Many experiments of this kind were performed by Spallanzani. The heart of a salamander was opened, and the blood continued to flow through the vessels for twelve minutes after the operation. The heart of a tadpole was cut out, yet "the circulation was maintained some time in several ramifications of the tail; while the motion of the blood in the large veins became augmented, that in the accompanying artery took a retrograde course towards the heart." The heart of the chick in ovo was destroyed immediately after contraction; "the arterial fluid took a retrograde direction, and the momentum of the venous blood was redoubled. The circulation continued in this manner during eighteen minutes."

Like the heart, therefore, the arteries are endowed with the properties of contractility and elasticity; and a little consideration will be sufficient to convince us, that were they not both elastic and contractile tubes, they would be unqualified for discharging the offices assigned them. The moment the left ventricle has poured its blood into the aorta, several retarding causes begin to operate, through which the velocity first imparted to the departing current gradually lessens as it moves to a distance from the heart. The friction between the blood and the sides of the vessels through which it moves,—the many curves and angles which it encounters while passing along tubes laid in every organ of the body—and the increasing area of these tubes as they ramify, are obstructions of such influence as would render it impossible for the heart to conduct the circulation without assistance. Since the area of the aorta or arterial trunk is less than the conjoined area of all its branches, it follows that the arterial system constitutes an inverted cone, the apex of which is in the heart and the base in the capillaries. And since it is a well-

known hydraulic law, that the velocity of a fluid in a tube is in an inverse ratio to the area of that tube, it likewise follows that the velocity of the blood along the arterial system must, in obedience to this law, decrease as it proceeds from the centre to the circumference.

Now, nature has done every thing to weaken the influence of these retarding causes. To lessen the effects of friction, the arteries are made elastic; to counteract the influence of curves and angles contractility is afforded; and to neutralize the tendency of a law which diminishes the velocity of a fluid as the vessel through which it moves increases, this contractile power augments as the vessel decreases. In consequence of the first provision, the impulse of the heart is transmitted along the vessel to as great a distance and with as little loss of momentum as possible; by the second a new impulse is added to the first; and by the third the strength of this impulse rises as that of the first declines. Were the arteries unyielding vessels, friction would operate at every impulse of the heart without the control of an opposing principle; but, by making them both elastic and contractile, and proportioning these properties to the varying necessities of the case, the impelling powers and resisting forces are equalized. Some from having overlooked this provident arrangement, have maintained that the velocity of the blood in the aorta is 1100 degrees quicker than that with which it circulates through the extreme vessels; and Hales has concluded that the blood in the capillaries of a frog's foot, which he says travels at the rate of two feet every minute, is six hundred and fifty times slower than that in the human aorta, the average velocity of which he estimates at eight inches in a second.

But many ingenious and well-conducted experiments have been made by Haller and Spallanzani, which clearly shew that, when the body is in a state of health, there is a very trifling difference between the velocity of the blood's movement in the large trunks and the minute vessels. When a small artery was opened, the blood issued with as much force and to as great a distance as when drawn from a large one; and when the microscope was employed, the blood in the capillaries frequently seemed to move even more rapidly than that in the trunks.

If it be considered how the two circulating powers already described—elasticity and contractility—are proportioned throughout the arterial system, it will not appear strange that the fact should be as is now stated. It is probable that the aorta is muscular as it issues from the heart, and that the farthest point of its most minute branch is elastic: but these two powers will not be found in the same degree in these two forms of the same vessel. Elasticity diminishes as we proceed from the heart; muscularity diminishes as we approach it. Their conditions are inverted. The stronger the contractility the weaker the elasticity; and the weaker the elasticity, the stronger the contractility. So that, as the strength of the heart's impulse upon the blood diminishes as the current leaves the centre, the strength of the contractile power in the smaller arteries through which it has to pass increases. And as the elasticity of the large arteries, which to them is essential, would be injurious to the small ones, this principle gradually decreases with the decreasing artery, until the capillary vessel becomes almost exclusively a muscular tube. A large artery near the heart needs not much contractile power, because the action of the heart gives a degree of momentum to the blood passing through such a vessel, which would not only render strong action in the vessel unnecessary, but inconvenient. But as this momentum weakens through the effect of the retarding causes already mentioned, increasing power in the artery is indispensable as a compensation for the decreasing influence of the heart. And since elasticity and contractility are antagonist principles, it were in vain to increase the contractility of the small artery while it was permitted to retain the elasticity of the large one, because any increase of its contractile power would be rendered useless by the preponderance of its elastic force. The elasticity of a large artery preponderates, because this elasticity enables it to dilate when the heart contracts, and thus to increase the action of the heart by diminishing the friction of the vessel; and the contractility of a small artery preponderates because this contractility enables it to make up for the deficiency of the heart's action, and thus to preserve the circulation in a tolerably uniform state.

Circulation through a large artery is, consequently, more an hydraulic,

through a small artery, more a vital process. Hence, in the sturgeon the aorta is bony, and the root of the same vessel is often ossified in man, without producing any change in the character of the circulation. The heart is the central organ by which the blood is put in motion, and circulates toward the circumference; the capillaries are the peripheral organ, by which the motion at first given to the blood is supported and assisted in returning toward the centre.

Action of the Veins on the Circulation.

It has been observed, that in the structure, course, and arrangement of the veins, there are several points which distinguish them from arteries. In the first place, they are thinner and less elastic, and muscularity has been generally denied to them. Secondly, they are crowded with semilunar folds of their lining membrane, termed *valves*, which are so disposed in their interior, as to offer no resistance to the blood in its progress to the heart, while they render any other course impracticable. Thirdly they are generally not so deeply-seated as arteries, but are comparatively superficial, many of them being covered only by the external skin. Fourthly, they are much more numerous than arteries, and anastomose much more frequently with each other; and, lastly, they are more capacious, and are supposed to contain two-thirds of the entire mass of blood. Now, a knowledge of these peculiarities will teach us the action of these returning vessels.

In several of his experiments upon salamanders, Spallanzani ascertained that the motion of the blood, during its return through the veins, was materially accelerated at every contraction of the heart. And it has been shewn, that the capillary arteries, in consequence of their increased contractility, operate at the circumference as the heart does at the centre of the circulation; differing in nothing but their degree of action. By the heart, or central power, the blood is propelled into and urged through the arterial trunks. As these trunks lessen into branches, the propelling power of the heart diminishes, while the contracting power of the tubes increases; and when the blood has reached the capillary or extreme vessels, it is then fully under the influence of a strong muscular agency. This muscular agency of the capillaries, aided by the impetus of the blood impelled onward from behind by

the heart and arterial trunks, enables this fluid to return through the veins. It must be recollected, however, that although we are thus tracing the different stages of the blood's progress through the system, it never stops in any period of its course; that the action of the heart is constant, and that the arterial trunks are ever full.

When a quantity of blood, then, has reached the capillary arteries, and is ready to be transferred into the capillary veins, three powers at least are in operation to effect its passage. The first is the muscular action of the arterial capillaries, the second is the action of the heart and arterial trunks, and the third is the momentum of a large column of blood already in rapid motion. These three agents, probably assisted to a small extent by capillary power, convey the blood, as it comes from the extremities of the arterial trunks through the capillary system, into the beginnings of the veins; but how far they are capable of propelling it along these vessels, it is not so easy to ascertain. For our present purpose it is enough to know that their action must extend a considerable way, and that in the structure, course, and number of the vessels through which the returning fluid has to pass, every facility is afforded to it. The veins are large and freely anastomose, in order that if any obstacle occur in the circulation of one tube, the blood may make its passage through another. They are crowded with valves, in order that the blood, which they contain, may be prevented from pursuing any other than its proper course, in order that the weight of the returning column may, as far as possible, be taken off the propelling powers, and in order that external pressure, or muscular action, or any neighbouring influence may be rendered available to the common object—the ascent of the blood in the veins. They are much less tortuous than arteries, that the impediment from curves, angles, and lateral friction may be small; and while the arterial system forms an inverted cone, the veins constitute a cone set upright, so that the returning blood has the advantage of a law which was a serious impediment to its progress along the arteries. When inverted and upright cones are here mentioned, we speak with relation to the course of the blood through them, and not to the position of the cones themselves. As to abstract position, the arteries are as much an upright cone

as the veins; since the apices of both cones terminate in the heart. But while the arterial blood moves from the apex to the base, the venous blood moves from the base to the apex; so that the current of the blood in the arteries, being viewed in relation to the position of the cone, is said to be along an inverted cone, but along an upright cone when in the veins.

Every facility being thus afforded to the return of the venous blood to the heart, the powers already specified operate with the greatest advantage; and when their influence begins to weaken as the current approximates the centre, a new agency comes into play, which must now be mentioned.

Suction power of the Lungs and Heart.

While treating of the action of the heart in propelling the arterial blood into the aorta, we said that the ventricle dilated as the auricle contracted, that the auricle dilated as the ventricle contracted, that the cause of the heart's contraction was its muscularity, that elasticity was the cause of its dilatation, and that this elasticity arose from the presence of a large quantity of cellular tissue, which is mixed up with the muscular fibres of this organ. It was likewise hinted, that one cause which assisted the auricle in filling the ventricle, was a partial vacuum formed within the latter by the action of its elasticity, and it will now appear that the same cause assists the venæ cavæ or trunks of the venous system, in filling the auricle when the ventricle is full.

If a caoutchouc bottle be filled with water and compressed with the hand, the fluid will be expelled from its mouth with a velocity proportionate to the compressing force. But the moment the pressure is removed, elasticity begins to operate, and if the mouth of the bottle be now immersed in water, a considerable quantity of this fluid will be drawn up into the bottle, in consequence of the vacuum formed within it. Let this illustration be applied to the action of the heart, and the nature of the new agent, which aids the other powers in returning the venous blood to the right auricle, will be easily understood.

When the right ventricle has poured its contents into the pulmonary artery, the auricle contracts, and immediately fills it. But the auricle has no sooner contracted than its elasticity again causes it to dilate, and thus a vacuum is formed

at the very extremity of the venous system. Meantime the blood, which in returning through the veins, being pressed upon in every direction from behind, moves on toward the heart, comes at length within the influence of this vacuum; instantly the suction power generated in the auricle begins to operate, and completes the circulation by drawing the rising current into the cavity of the auricle.

To revert again for a moment to our illustration of the elastic bottle. Suppose that, in place of allowing this bottle to be exposed to the action of the external atmosphere during the experiment, it be introduced within the exhausted receiver of an air-pump, while, at the same time, by adjusting a pipe to its mouth, we connect the bottle within the pump with a vessel of water on the outside; it is evident that, since the pressure of the air is removed from the surface of the bottle, while it continues to act upon the surface of the water, the fluid will be drawn through the pipe into the cavity of the bottle with a very considerable force; with a force regulated by the proportion which the surface of the water bears to the surface of the vacuum within the bottle.

Now, it is supposed that the heart, during a healthy state, is placed in circumstances very similar to those in which the elastic bottle stands while under the receiver of the air-pump. Until, however, we proceed to the subject of respiration, and have the anatomy of the pulmonary system before us, it will be impossible to present the reader with any intelligible description of this doctrine. For the present, he must rest satisfied with the assumptions that such a vacuum exists; that during inspiration, the cavity of the chest being much enlarged, the pressure of the external atmosphere upon it is materially diminished; that the parts which it encloses are for the time in a partial vacuum; and that, from the connexion subsisting between the heart and lungs, a considerable portion of this vacuum takes place in the cavity of the pericardium, or bag, which surrounds the heart. The consequence is, that the heart works within the pericardium as the elastic bottle works within the exhausted receiver; with this difference, that the vacuum within the latter is constant, while it only occurs in the former during every inspiration.

If a ligature be put around a vein,

the blood contained by that portion which lies between the ligature and the heart, continues, without interruption, to pursue its course to the auricle; proving that, although all communication has been thus destroyed between this section of blood and the general current, there is still some power existing between the ligature and the heart. The following experiment is given to show that the influence which this suction power exerts upon the course of the venous blood is not only certain, but considerable. The left jugular vein of a horse was exposed and tied. About an inch below the ligature a large-sized flexible catheter, having a spiral glass tube adjusted to one end, was introduced into the vein by the other extremity, pushed down toward the heart as far as it would freely go, and preserved in this situation by having a ligature thrown around it and the vein. The point of the spiral tube, which had an aperture in it that had been hitherto closed by the finger, was now immersed into a cup of water, coloured with Prussian blue, and the finger was removed. The moment the tube was introduced into the cup the blue fluid rose rapidly in the tube. "The sun," says Dr. Barry, "happening at the moment to shine strongly on the tube, I saw in the most satisfactory manner the undissolved particles of blue pass up from the cup and round the spiral during inspiration, and halt and return slowly towards the cup during expiration. Not a drop of blood was seen to enter the tube, but bubbles of air sometimes appeared upon the surface of the liquid in the cup during expiration. The breathing being audible allowed me to keep my eye steadily fixed upon the motion of the liquid, and to ascertain, beyond all possibility of deception, that this motion was entirely dependant upon the movements of respiration."

The strength of this suction power in the heart is not easily measured, nor is it known with certainty how far along the venous system its influence extends; but it is obvious, from the very structure of the heart, that such a power does exist within it; and, from the observations now made, it appears that this innate suction power of the heart is materially increased by the elasticity of the lungs; or, in other words, that the heart is an elastic muscle placed within a vacuum. Viewing it, therefore, as both a forcing and a suction pump; as a hollow organ which empties its cavities by

contraction, and fills them by elasticity, many phenomena receive elucidation which it would be otherwise difficult to explain. The superficial course of the veins, the deep-seated position of the arteries, the continuous stream in which venous blood flows, and the interrupted current of arterial blood; the strong elastic structure of arteries, and the pliant compressible texture of veins; the turgidity of the veins of the neck and face during expiration and coughing; the great size of the right auricle over the left; the theory of palpitation, and the cause of the pulse;—these and many other interesting points, which our limits prevent us from noticing more largely, can be accounted for when it is known that atmospheric pressure is to be enrolled among the circulating powers, as second only in importance to contractility. The veins are pliant and superficial to give full effect to the action of the atmosphere; while the arteries are deep seated to avoid pressure, and elastic that they may, after yielding to the impulse given to the passing current by each pulsation of the heart, assist this organ by their reaction in moving the vital fluid toward the capillaries. The current in the arteries is salient or interrupted, because it depends upon the alternate contractions of the heart and dilatation of the arteries; while that in the veins is continuous, because it is moved on by more continuous agents. For the same reason is it that there is an arterial, but no venous pulse. This phenomenon is strongest at the heart, because there contraction is the strongest; and it gradually declines as we leave the centre, because as the blood departs from the centre, it is leaving the principal impelling agent; and, therefore, the impression made upon the artery at each pulsation of the heart lessens as the distance between it and the heart increases.

General Remarks upon the circulating Powers.

Such, then, are the principal agents by which the circulation in man is conducted. Some others have been mentioned, as contraction of the muscles, pressure of the viscera, the movements of the diaphragm, (of which we shall speak immediately,) and capillary attraction. But, although all of these may be considered auxiliary agents, their action must be always trifling, and may be sometimes adverse. Contraction

of the heart and capillaries, elasticity of the heart and arteries, and suction power of the heart and lungs, are the three chief circulating agents, to which the execution of this important function is to be ascribed; and the consummate wisdom, with which these agents are so adapted to the varying circumstances of the circulation, can be only imperfectly estimated even when fully understood.

We have seen that the force of the heart's action has been fixed at a certain number of pounds and grains, just as we might take the weight of a piece of dead machinery, and that the velocity of the blood has been measured throughout the different stages of its course, with an inch and line calculation. But the folly of such estimates must now be obvious. As the relations between the moving agents are ever changing, the degree of motion which they generate must be equally variable. The influence of the heart upon the vital current varies with the distance; the contractility of the arterial trunks increases as they leave the heart; the elasticity of the arterial capillaries diminishes as they approach the veins; and, although the absolute pressure of the atmosphere upon every part of the external surface of the body must be the same, that is, fifteen pounds upon every square inch, the operation of a vacuum within the chest will render the effect of this pressure upon the motion of the venous blood greater in a direct ratio to its proximity to the vacuum. Thus, in perhaps every inch of sanguiferous vessel there is a new combination of the sanguiferous agents; and it is, therefore, idle to circumscribe within one general calculation the operation of powers, whose proportions are as different in different parts of the system, as the nature of the tissues through which the blood circulates.

Besides, in different individuals, and even in the same individual at different periods, the force of the heart's action and the activity of the vessels are very various. In the melancholic the circulation is languid; but in the sanguine it is quick. When enlivened by hope, or encouraged by prosperity, the vital current flows with ease and freedom; but when grief or adversity sinks the spirits this function is sure to sympathize. In youth the pulse is frequent; in manhood it is firm; in age it is weak and slow. In short, the heart is so en-

tirely the slave of mental emotion and physical circumstance, that its action may alter every hour in the day, or every minute in the hour; and the only certain facts which we can vouch for on the subject of the blood's velocity are, that it is somewhat greater in the large arteries than in the small, and somewhat less in the small veins than in the large; that as it issues from the left ventricle and enters the right auricle it is quicker, and as it passes from the arteries into the veins slower, than during any other periods of its course.

Uses of the Circulation.

The objects for which this complicated function has been so perfectly established, and is so faithfully maintained, are many and important. Nutrition, secretion, respiration, absorption, sensation, and motion, depend upon its performance. No new part could be formed, no new fluid could be elaborated, no excrementitious matter could be removed, no sensation could exist, and no motion could be effected without a heart, arteries, and veins. The process of digestion on the one hand would go on in vain, and the function of absorption, on the other, would be useless. Were there no arteries to convey the chyle, which has been elaborated in the stomach, to every organ, digestion might proceed for ever without supporting life; and were there no veins to receive the refuse matter of the system from the absorbents as they take it up, nutrition could not possibly be accomplished; the wheels of life would be clogged with excrementitious matter, the removal of which is as necessary to existence as the deposition of nutrient particles. To enter at present, however, into subjects of such extent would be irrelevant. Some of them will soon come before us in a specific form, and others will be noticed with more advantage in another place. A few general observations will be sufficient to establish their importance, and also to shew the intimate connexion which the circulation has with every other animal function.

The anxiety which nature exhibits to supply every organ and tissue with sufficient nutriment, is apparent in the minute distribution of the blood vessels. There is no part so small as to be overlooked, and no member so large as not to be abundantly supplied. There is no texture so impenetrable, which is not tra-

versed by giving and receiving vessels; and there is no organ so distant which arteries do not reach, and from which veins do not rise. From microscopical observation, Leuwenhoeck was induced to conclude, that there were upwards of 1,000 different circulations within every square inch of the human body; and such minute distribution of the blood is not a more striking feature of this function, than the undeviating accuracy with which every nutrient particle of the general mass is deposited in its proper place. Osseous matter is laid down where bone is necessary; fleshy fibre is formed where muscle is required; and cellular tissue is secreted where neither bone nor muscle could be substituted. Perhaps, in the wide range of Nature's splendid operations, there is not to be found a more perfect, or a more extensive series of effects, resulting from a less complicated piece of mechanism, than is witnessed in the circulating system: a mechanism whereby tissues the most different are constructed out of the same fluid, and vessels externally alike elaborate secretions which have scarcely one point in common. Between the blood going to the stomach, and that which supplies the kidneys, no difference is discoverable; yet the fluids secreted by these organs are totally dissimilar; the vessels which supply the teeth and those which support the brain, appear externally alike, yet there are not two substances in nature more opposite than nerve and enamel. Muscular fibre is never deposited where cartilage was wanted; bile is never eliminated where saliva should be formed. Each tissue is deposited in its proper place; and not only in its proper place, but in its proper time; and not only in its proper time, but also in its proper quantity. When a bone is broken, osseous matter is immediately thrown into the fracture by the vessels of the part. When a nerve is divided, nervous matter is brought to the divided organ, and the nerve is healed. When cuticle has been destroyed, a new layer of skin is instantly substituted. And when a piece of flesh has been cut out, granulations instantly arise, and fill up the cavity which had been formed. But no sooner has the bone united, than the influx of ossific particles ceases; and the moment that granulation has raised the wounded part to a level with the surface, the deposition of muscular fibre stops, and

the formation of skin begins. Did the production of skin commence before granulation had filled up the cavity, deformity would be the consequence; or, did granulation continue after the cavity had been filled up, the formation of skin would be prevented. Granulation continues, therefore, as long as it is required, and ceases when its continuance would be hurtful, and the secretion of skin begins only when the other process has been completed, and terminates as soon as the part is perfect.

Among the many objects contemplated in the circulation of the blood, one of the most important is its purification in the lungs. It has been already shewn that in birds and the mammalia, a second heart is added to the ordinary circulating system of cold-blooded animals, for the specific purpose of enabling the blood to undertake a second circulation through the lungs, previously to its distribution throughout the body. This lesser circulation in man is as constant and as necessary as the first; and the objects which it accomplishes are of the very same nature with those attained by the general circulation. During the passage of the blood through the body, nutritious matter is thrown out, and refuse matter is taken in; solids are formed, and fluids are eliminated: and during its passage through the lungs, vital properties which it had lost are received, and noxious qualities which it had contracted are removed. Secretion and nutrition are thus performed by both circulations; but before the nature and extent of the changes which the blood experiences by respiration can be duly estimated, the anatomy and theory of this function must be understood.

ON RESPIRATION.

It has been already observed, that wherever there is an organ appropriated to the function of digestion, there must be some kind of circulating system for conveying the digested nutriment where it is required. In like manner, wherever there are organs appropriated to the purposes of the circulation, there must be a respiratory apparatus for renovating the blood, as it deteriorates in its passage through the body. These three functions are inseparably connected. Stop the circulation, and diges-

tion will cease; destroy digestion, and the circulation will cease; and let respiration be arrested, and both of the other processes will soon be at a stand. Chyle is not more necessary for the formation of blood, than air is for its purification; and venous or deteriorated blood is as useless to the general system as chyle, before it has been subjected to the influence of the air. The lungs may thus be regarded as a second stomach, and respiration as a second digestive function. When food enters the stomach, its nutrient particles are separated from the crude mass and converted into chyle. When air enters the lungs, its vital properties are separated for the purification of the blood. The nutritious ingredients of both substances are extracted and made subservient to the purposes of life, and their residual principles are expelled as useless and hurtful. The stomach digests food, the lungs digest air. Digestion is necessary to form chyle, and respiration is necessary to convert that chyle into vital fluid; so that the proper animalization of our food is completed in the lungs, and not in the stomach.

"To breathe and to eat" are expressions, therefore, more synonymous than at first view they may appear; and "to expire and to die" have been long known as different modes of communicating the same idea.

The intimate connection between digestion and respiration is still more strongly shown by the fact that in many animals, of which the simple structure is incompatible with complex function, the same organ is made to serve both as a digestive and a respiratory apparatus. In the lowest forms of zoophytes, the skin both respire and digests,—inhales both air and water. In many insects, a portion of the intestinal canal performs the office of lungs; and in some the intestine opens into the respiratory cavity. Even in man it is certain that the skin is a breathing and an absorbing organ; and calculations have been made by physiologists relative to the quantity of air it expires and of water it inhales, throughout the day. Finding, then, that the same texture which forms blood can also purify it; and having seen, when on the subject of the circulation, that the dorsal vessels of insects might be considered, with as much propriety, an intestinal canal as the first rudiment of a circulating system, it is natural to expect that there should be as great a variety in the structure of the respiratory apparatus as in the ma-

chinery of the digestive and circulating functions, and that the steps by which it rises to its most perfect state should be analogous.

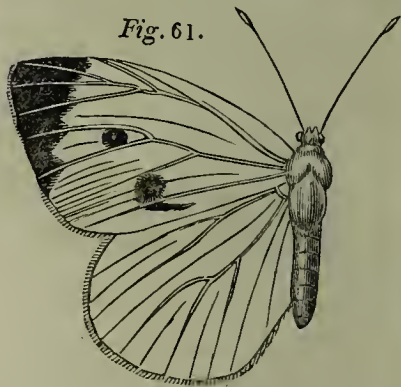
The habits of different animals are so varied, and the elements which they inhabit so opposite, that to support a function so universal as that of respiration, and for the efficient discharge of which a constant supply of air is necessary, requires a mechanism difficult of contrivance. Animals which live in water cannot breathe by the same organs as those which live in air; and worms, which lie buried in the bowels of the earth, must exercise a very different function from birds, which respire in elevated regions of the atmosphere. Nature has accordingly adapted her form of apparatus to the necessities of the animal, and the success with which this adaptation has been made will be abundantly apparent as we proceed.

In some creatures, whose simple systems require little nourishment and admit of little expenditure, this function is exceedingly limited, and no specific organ is set apart for its performance. In the *hydatid*, for example, which is merely an animal bag filled with fluid, respiration is conducted as it is in the vegetable, by the surface of the skin; and in zoophytes generally the blood is aerated by the same organ which absorbs the nutriment out of which it is made. In such beings the best glasses have as yet failed to discover a distinct respiratory apparatus; and, therefore, some have concluded that they do not respire. But when the air with which they have been for some time surrounded, is examined, it exhibits those alterations in its properties which respiration is known to make; and when they are immersed in fluids, from which all air has been expelled by boiling, they languish and die. Although, therefore, there be every reason to believe that the skin, even in the most perfect systems, has some community of office with the lungs, respiration by the skin must be regarded as the first and lowest form of this function. And when it is considered that the majority of such creatures as respire in this way are inhabitants of water, it will be evident, as well from the inconvenience of the medium as from the imperfection of the apparatus, that in them little air is necessary for the purposes of life.

When we ascend another step however in the scale of being, this func-

tion is more amply developed. The air is no longer confined in its action to the surface; it has access to every part of the body by means of air-tubes, called *tracheæ*, which are not unlike arteries in form and distribution (*fig. 61.*) They circulate air as the arteries do blood; they send branches into every part;

Fig. 61.



Represents the distribution of the tracheæ in the wing of the butterfly.

and they open upon the external surface by apertures, called *stigmata*, (*fig. 62,* and *fig. 63,*) which are differently

Fig. 62.



Lateral stigmata, as seen in the bee-worm.

Fig. 63.



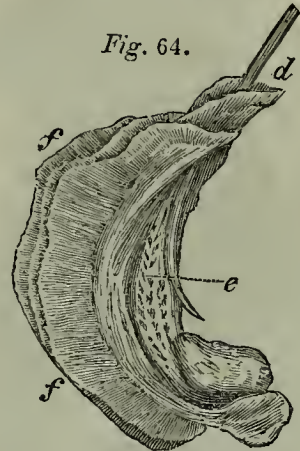
The Microscopic Louse, shewing its surface covered with spiracula.

formed, and exhibit great variety in their number. In *grasshoppers* they consist of fissures formed of an anterior

and posterior lip, which being surrounded by muscular fibres, can close or open at pleasure. In the *willow caterpillar* they are circular, and in the larva of the *cockchafer* they are guarded by a cribriform membrane, through small apertures in which the air is admitted. Since there is no texture or organ from which these air-vessels are excluded, not even the membranes composing their own trunks, the bodies of such insects as breathe by tracheæ may be looked upon with some force of analogy as little else than lungs. To have set apart in them a single organ, large enough for the purposes of respiration, and yet proportioned to the size of the general system, would have been impossible. From the habitudes of insects, it was much better, and from the peculiarities of their circulation, it was much easier, to send air to their blood, than it was to send their blood to the air. In them, accordingly, the respiratory and sanguiferous systems are reversed, when they are compared with those which obtain in man. In the human system it is the blood which goes to be purified by the air; but in insects it is the air which goes to purify the blood. In insects the body is traversed with air-tubes in place of blood vessels, and their whole system breathes; but in man the respiratory apparatus is limited to a certain spot, and the function is performed by a single organ. The quantity of air consumed by such animals is large in proportion to their size; and when the active habits which distinguish many of them are considered, the relation between the extent of this function and the energy of life can scarcely be overlooked. Insects among the cold-blooded animals are what birds are among the hot—the only class which can fly, and most of those among them which have no wings, as the common *centipede*, excel in a vivacity of habit and tenacity of life. Several species of this class, which are obliged to breathe under water, and yet are furnished with tracheæ, manage it by a very simple contrivance. In consequence of the glutinous matter with which the hair upon their skin is covered, the water is prevented from coming into contact with their surface; so that they literally breathe within an air-bubble, and swim in a kind of natural diving-bell. The *water-spider* and *water-beetle* belong to this description of insects. The *nepa* is also an aquatic insect, but not being

encompassed with an air-bubble, it is compensated for the want of it by having respiratory tubes near the anus in the form of long bristles, through which it can obtain air from the surface of the water.

The ordinary method in which aquatic animals, that have to remain constantly beneath the surface of water, respire, is by *branchiæ*, or *gills* (fig. 64.)



Gills of an Oyster. *d*, the triangular canal through which water is sent to the gills; *e*, the holes by which water is sent to every feather of the gills; *f, f*, the fimbriated extremities of the gills.

Many insects and worms, all the crustacea and fishes, breathe by gills only. These organs are very different in construction, situation, and number. In the *thetis* they appear as fourteen distinct tufts on each side of the back. In the *glaucus* they are fin-shaped. In some they are disposed in the form of tiles, in others they are pencils of small filaments. Sometimes they are situated upon the external surface, but more generally they are found in the interior of the body. In the *decapoda* they are attached to the base of the feet. In the *branchiopoda* they are placed under the tail and fins, and in the *cephalopoda* they are enclosed within a bag, which communicates externally by a funnel-shaped aperture upon the neck. This bag is muscular, and can be filled and emptied as fresh water is required for the branchiæ. In the *aphrodite aculeata* their number amounts to forty pairs; the *lumbricus marinus* has fourteen pairs, which occupy the middle of the back; and in the *sepia* there are two only, one on each side of the peritoneal sac.

The branchiæ in *fishes* are situated on each side of the neck, and have a free

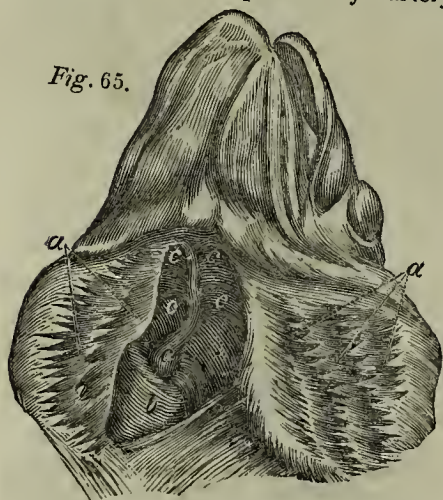
communication with the mouth, of which they may be considered as forming the back part. They are composed of laminae, fixed by their base to the convex sides of cartilaginous arches, but free and unattached at their superior extremity. These laminae are long, narrow, and pointed, and set so closely to each other that they resemble the barbs of a feather, or the teeth of a comb (*fig. 65, a, a.*) The pulmonary artery,

strongly impinged against the coats of the blood-vessels, may more certainly act upon the blood which they contain.

Three different types of the respiratory function have now been noticed. In zoophytes and a few species of worms, the external skin is the only breathing organ. A very large proportion of insects respire by tracheae, or air-vessels, and aquatic animals breathe by means of branchiae, or gills. The next decided step, which is taken towards the establishment of a more perfect function, is the introduction of bodies called *lungs*, which are membranous bags, divided into cells, and adapted for containing air and blood.

But between this and the preceding forms a few animals are found, whose respiratory apparatus may be mentioned as the connecting link. These are possessed of a double set of breathing organs—branchiae and lungs. By the former they are connected with fishes, insects, and worms, and by the latter, with mammalia, birds, and reptiles. In the *siren* there are three tufts, or branchiae, on each side of as many vertical slips placed in succession behind the head, and through which water received by the mouth is forcibly discharged. In the *proteus* there are likewise three branchiae of a deep-red colour, which open by three distinct apertures upon the sides of the skull. But in both *siren* and *proteus* there are, besides these aquatic organs, two cylindrical bags situated in the abdomen, which act the part of lungs. Each of these bags consists of a single cavity, internally lined with a very vascular membrane, and communicating with the external air by an air-pipe or trachea, which opens upon the surface between two rounded margins. The *tadpoles* of frogs, toads, and salamanders exhibit a similar union of respiratory organs.

These creatures, thus anatomically allied to aquatic and aerial beings, are called *amphibious*; because being possessed of both gills and lungs, they can respire equally well in air and water, as circumstances may require. In addition to these many other species have been very generally esteemed amphibious; as, for example, *otters*, *seals*, *frogs*, and *lizards*, but it is now ascertained that they can breathe air only, and when they descend into water, do so merely for the sake of procuring food. Blumenbach observes that *water-newts*, when placed in a deep vessel filled with



The Gills of a Trout. *a, a*, the fimbriated texture of the gills; *b*, the heart; *c, c, c*, the bronchial, or pulmonary artery, which conveys all the blood from the heart to the gills.

which rises from the ventricle of the heart in fishes, is spent upon the gills (*fig. 65, c, c, c.*) Each pair of laminae receive a branch from it, which ascends along their internal edge, giving off many lateral branches as it proceeds. When it reaches the apex it pours its blood into returning vessels, which unite after they leave the gills and form the aorta, by which the rest of the body is supplied. During this circulation of the blood upon the gills, the required alterations are effected, and the use of these laminae is to afford a sufficient surface for the play of vessels, that the air contained within the water which the fishes swallow, (in order to drive it among the branchiae,) may act upon the largest quantity of blood with the greatest possible advantage. The extent of surface thus obtained is very great. Monroe has calculated that in the gills of the *skate* it is nearly equal to the whole external surface of the human body, or to more than fifteen square feet. Along this vascular surface the water is made to play with considerable force, that the air suspended in it, by being more

water, are seen to rise frequently into the air in order to breathe; and it is well known to fishermen that *turtles* cannot continue beneath the surface for any considerable length of time.

With the exception of the *batrachia*, reptiles inspire air alone, and can, therefore, only breathe with lungs. These organs are, however, at first very simply constructed. In place of consisting of a great number of cells, connected together by cellular substance, and enclosed within one common envelope, as they appear in the *Mammalia*, they are merely large bags or sacs, lined with a very vascular membrane, into which air is alternately admitted and expelled through a trachea, or air tube, which communicates with the mouth. In the *aphidia* this air-tube opens into the bag by a single orifice. In the *crocodile* it divides into bronchi before reaching the lung; and in the *turtle* each bronchus penetrates the substance of the lung to its remotest point.

It has been already stated, that in the *cephalopoda* the branchiæ are enclosed in a bag, very similar to this pulmonary sac, or rudimentary lung; and that in the *siren* the branchiæ and the bag are separated, and placed in different parts of the body. Here the branchiæ are entirely removed, and the bag alone remains; so that the steps are slow but obvious, by which organization rises to maturity. The lung of a *salamander* is exactly like the branchial bag of the *cephalopoda*, after the branchiæ have been removed. In the *colubus natrix* the same structure is preserved, with this exception, that the bag is larger in proportion, and that the internal surface of its anterior half is beautifully reticulated like the interior of the second stomach of ruminating mammalia. This appearance may be regarded as the first attempt at the division of the sac into cells. In the lungs of a *frog* these cells are very evident, and in the *turtle* they are numerous and large. *Serpents* have only a single sac or lung, which extends from the œsophagus to the lower margin of the liver; the *siren lacertina* has two, which stretch to the end of the abdominal cavity, and in the *cameleon* they are so large, that this creature can, by inflating them, swell itself up to an amazing size. Reptiles, in this respect, differ from all other animals. In birds and the mammalia the air-cells of the lungs are small but numerous, and well adapted for the reception of air; their

lungs are compact and of moderate size, but amply supplied with blood. The lungs of reptiles, however, are large, floating, and unconfined among the viscera of the abdomen; divided into few cells, and scantily furnished with vital fluid (*fig 66, f, f.*) This difference of respiratory

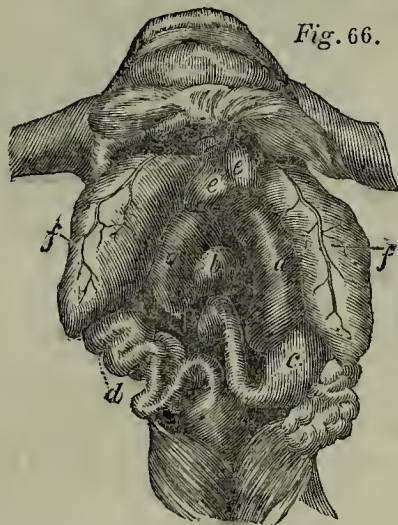


Fig. 66.

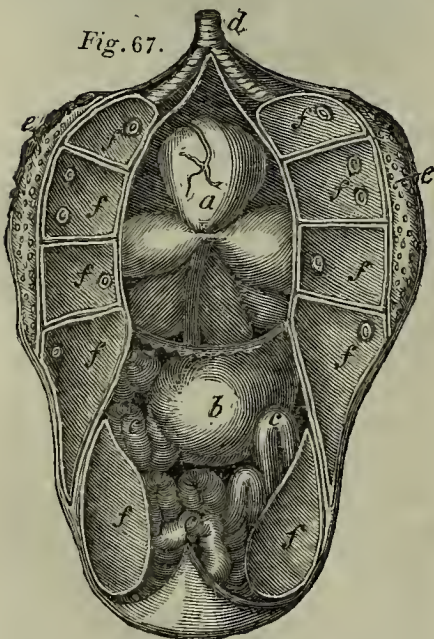
The Lungs of a Frog. *a a*, the liver; *b*, the spleen; *c*, the stomach; *d*, the intestines; *ee*, the heart; *ff*, the lungs.

apparatus between reptiles and warm-blooded animals is partly accounted for by the difference of their circulating functions. In the latter all the blood must be passed through the lungs, and must be purified by the air before it can circulate through the body; while in the former not more than one-third requires to be subjected to such an ordeal.

Before leaving the subject of respiration among cold-blooded animals, we cannot refrain from a few remarks upon the wisdom with which the deficiencies of one function are compensated by the greater development of another. Thus, in fishes all the blood passes through the gills before it circulates through the system; while in reptiles a portion only is sent for purification to the lungs. The influence of these different arrangements, however, upon the blood is not so great as at first view might be imagined. These two classes of beings inhabit very different elements. The skate breathes in water, the frog breathes in air; the blood of the one is freely exposed to the purifying principle, that of the other is acted upon by it only through the instrumentality of an inconvenient medium. While, therefore, only a portion of the blood in reptiles can be purified

during each circulation, seeing that a portion only is exposed to the purifying principle, the blood in fishes can also be only partially purified during each circulation, since it is exposed to a medium which is only partially qualified for that purpose. In the one case there is an imperfect circulation, in the other an imperfect respiration; and since it must be a matter of little moment whether ten ounces of blood be only half purified, or the half of ten ounces be wholly purified, the ultimate effect of this difference of arrangement in these different animals must be very much the same. The perfection of the medium in which reptiles live compensates for their pulmonary circulation being partial; and the complete pulmonary circulation of fish compensates for their imperfect medium. Both classes of animals circulate blood alike cold, and execute functions alike tardy.

The respiration of *birds* is distinguished by many interesting peculiarities, (*fig. 67.*) Formed with wings and other or-



Lungs of the Ostrich. *a.* the heart; *b.* the stomach; *c, c.* the intestines; *d.* the trachea; *e.* the lungs; *f, f, f.* air-cells, in which are also seen the tubes by which these air-cells communicate with the lungs.

gans for the purposes of flight, the loose and ponderous lungs of reptiles would have been highly inconvenient; and possessed of a double heart for conducting a double circulation, such a respiratory apparatus as could expose a sufficient quantity of blood to a sufficient

quantity of air was indispensable.—Means have been accordingly employed for the attainment of these objects.

To prevent the inconveniences of motion, the lungs are not free, but fixed; not allowed to float without restraint in the cavity of the chest, but nixed down between the ribs on each side of the dorsal spine. And to ensure the full arterialization of the blood, without interfering with the natural habits of the animal, air is allowed to every organ, and respiration is carried on in every part. In addition to two solid and fleshy lungs, which are firmly fastened down between the intercostal spaces in the back part of the chest, there are sacs or bags of considerable size, not unlike the lung of a salamander, scattered over the other viscera of the abdomen, which communicate with the lungs and with each other, are formed to contain air, and fill and empty as the bird inspires or exhales. Similar air-cells exist externally between the muscles; the bones themselves, which in the mammalia contain marrow, are in birds filled with air; and it is a remarkable fact, that the quantity of air which they individually contain is proportioned to the influence which they exert on the loco-motion of the body. Thus, in the *eagle* and other birds of flight, the bones which support the wings are filled with air; while in such as the *puffin*, whose wings are unequal to any lengthened flight, or the *ostrich*, which prefers to run, air-cells are found in greatest numbers within the bones of the leg and thigh.

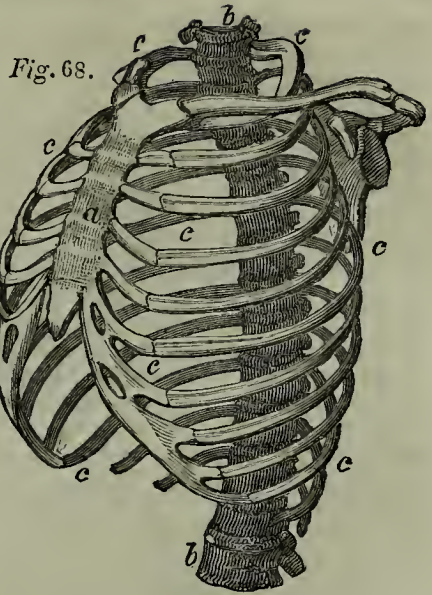
The manner in which these pneumatic cavities communicate with the proper lungs of the bird, is very simple. When the trachea enters the lungs, it divides into many branches. Some of these are wholly expended upon the texture of these organs, while others, without giving off any branches in their course, proceed directly to the surface of the lung, upon which they terminate by open mouths. These air-holes, or branchial apertures, are covered by some of the air-cells which surround the lungs; these air-cells open into others, and thus a free intercourse is established with every part of the system; so that the air which enters the lungs by the trachea from the fauces, can pass out of them through the air-holes upon their surface into the air-cells, whether they lie within the bones, among the muscles, or in the abdomen.

The beauty of this contrivance is equalled only by its importance. Independently of a perfect supply of air being thus furnished at all seasons, for the purposes of respiration, without any inconvenience to the general system, the relative weight of the body is materially diminished, the difficulty of breathing in a very rarified atmosphere is counteracted, and the necessity of a frequent respiration during rapid flight may be dispensed with. It is also probable, that while on wing, birds can rise or fall at pleasure, by filling or emptying their air-cells, as fishes do by inflating or collapsing their air-bladder, and it has been conjectured by Mr. Hunter, that these cells are in some degree connected with their musical faculty.

In the *mammalia*, this function attains its most perfect state. Into the construction of their pulmonary system every anatomical and physiological advantage has been introduced which could render it complete; the superior mechanism of their lungs, the number of their air-cells, the minuteness of their blood-vessels, their position within a case which can contract and dilate at pleasure, and the variety of means which are employed to fill and empty them with air, while they themselves continue passive,—these and many other circumstances, which will hereafter receive farther notice, indicate the anxiety which has been displayed to endow this class of beings with a respiratory apparatus worthy of working in connection with that admirable circulating system which they enjoy, and which has already been described. But, without premising any additional remarks upon the respiration of the *mammalia* generally, we shall at once proceed to explain it as it appears in man, and with this view shall, in the first place, briefly describe its anatomy, secondly, its mechanism, thirdly, its theory, and lastly, its effects.

Anatomy of the Pulmonary System.

The thorax or chest is a conical cavity, (*fig. 68.*) the apex of which is formed by the neck, and the base by a muscle called the diaphragm, which separates it from the abdomen. Externally it is protected by bone; on the front by the breastbone, (*fig. 68, a*); behind by the spine or backbone (*fig. 68, b, b*), and on each side by the ribs (*fig. 68, c, c, c, c.*) These bones are connected by ligaments and joints, and give attachment to muscles which serve to regulate their motions. Within, it is



Trunk of the Human Skeleton. *a*, the sternum or breast bone; *b b*, the spine; *c c c c*, the ribs.

divided by a lining membrane called the *pleura* into three large compartments, independent of several smaller and less important cavities. In the largest of these is contained the right lung, in the smallest the heart, and the left lung lies within the third compartment (*fig. 75, a, b, b.*)

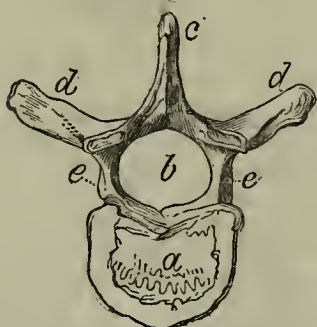
All the parts concerned, therefore, in the respiration of man may be arranged into three divisions. First, the bones which form the respiratory cavity; secondly, the muscles by which these bones are moved and the size of the cavity regulated; and thirdly, the respiratory organs contained within the cavity. Belonging to the first division are the sternum or breastbone, twelve dorsal vertebræ, and twenty-four ribs. Several pairs of muscles, and the diaphragm, constitute the second division; and the trachea, larynx, and lungs are comprehended by the third.

Between the anterior extremities of the ribs and situated over the heart, lies the *sternum*, or breastbone. (*See fig. 68, a.*) It is a light and spongy bone, depending principally for its strength upon the numerous ligaments which cover it. In the child it is divided by cartilaginous partitions into eight pieces, which, as life advances, are reduced to three, and in old age are united into one. Its lower end gives rise to a sharp-pointed cartilage which lies over the stomach and may be felt externally: its upper end is somewhat hollowed in the middle, to allow

the trachea or windpipe to pass under it; and on each side there are seven oval depressions for admitting the cartilaginous extremities of the first seven ribs. The connections and situation of the sternum prevent it from having any motion of its own; it therefore follows to a certain extent the movements of the ribs to which it is articulated.

The *spine*, or what is vulgarly called the backbone, (*fig. 68, b, b,*) is composed of twenty-four very irregular bones, which are separated from, yet connected with, each other by as many intermediate pieces of cartilage. These bones are called *vertebræ*, and the cartilages which connect them are styled from their position *intervertebral cartilages* (*fig. 69.*) These twenty-four

Fig. 69.



A dorsal Vertebra. *a*, body of the vertebra; *b*, the canal for containing the spinal marrow; *c*, the spinous process; *d d*, the transverse processes; *e e*, the articulatory processes.

vertebræ are arranged into three classes; the cervical, dorsal, and lumbar vertebrae. The first seven are the cervical, because they belong to the neck; the next twelve are the dorsal, because they belong to the back; and the last five are the lumbar, because they are situated in the loins. Peculiarities of form as well as of situation, distinguish these different orders, but as a knowledge of the dorsal vertebrae will be sufficient for our purpose, the present description will be confined to them. Each of the twelve dorsal vertebrae consists of a body, four articulating processes, two transverse processes, and one spinous process. The *body* is formed of soft and spongy bone, which is circular before, flat towards the sides, hollowed out behind into a crescentic shape for containing the spinal marrow, and somewhat concave both above and below for the accommodation of the intervertebral cartilage. Situated laterally on the body of the vertebrae, are the four *articulating processes*; each

vertebra being connected with the two immediately adjoining it. Two of these processes are situated near its upper surface to articulate with corresponding processes belonging to the vertebra above, and two are placed near its under surface to join with those of the vertebra below. The two superior articulating processes of one vertebra are thus connected with the two inferior articulating processes of another, and these points of union not only co-operate with the intervertebral cartilages in keeping these two vertebrae together, but permit a slight rotatory motion of the one upon the other. The *spinous process* projects directly backwards from the body of the vertebra, and may be felt externally by moving the finger along the spine; while the two *transverse processes* stand out on either side, and have the ends of the ribs attached to them.

The *ribs* (*fig. 68, c, c, c, c*) are twelve long, curved bones, which are joined behind to the dorsal vertebrae, and before to the sternum, or breast bone. The upper seven are called true ribs, because they are immediately connected to the sternum; the lower five, false ribs, because they are implanted into each other by cartilaginous appendages, and are only supported by the sternum through the medium of those above. They are concave internally, that the lungs may have more space to expand; externally convex, that their arched form may enable them more effectually to resist external injury; and they are attached to the spine at an acute angle, that they may not be moved out of their ordinary position without enlarging the dimensions of the chest. The *head*, or vertebral end, of each rib is so articulated with the spine, as to be fixed upon the intervertebral cartilage, and is connected on each side with the vertebrae which this cartilage separates. About an inch from this head there is a small bump upon the back or convex surface of the rib, which articulates with the transverse process of the vertebra below, and a little above this bump there is a second, to which strong ligaments are attached for the surer connection of the rib and vertebrae. The anterior or sternal ends of the ribs are not bony, but cartilaginous. The cartilaginous extremities of seven of them are jointed to the sternum by regular sockets or small oval cavities, and the other five are implanted into each other.

The motions allowed by these articulations are limited, but sufficiently ex-

tensive for the purposes of respiration, when in a healthy state. During inspiration the chest expands for the reception of air, and during expiration it contracts to expel air which is no longer useful. Two motions, therefore, are all that can be required—an upward and an outward motion. The distance between the spine and sternum is increased by the former, that between the ribs by the latter. Now these two motions, and only these, are performed by the ribs, and their articulations are such that they cannot execute one of these movements without the other. By their sternal ends they can rise and fall, because the sternum, into which they are articulated, is a moveable bone, and depends for its movements upon the motions of the ribs; and by their vertebral ends they can move outwards as their sternal ends rise. But their sternal ends cannot rise unless their vertebral ends rise also; and their vertebral ends cannot rise without pushing the sternum out, and thus increasing the short axis of the chest in every direction. Had they been articulated at right angles with the spine, the size of the chest must have been diminished, whether they rose or fell. But as their oblique position is their natural state, they cannot rise without moving outwards, and they cannot move outwards without increasing the capacity of the thorax. During inspiration, therefore, the chest must be expanded, and during expiration it must contract; and these are the two conditions required.

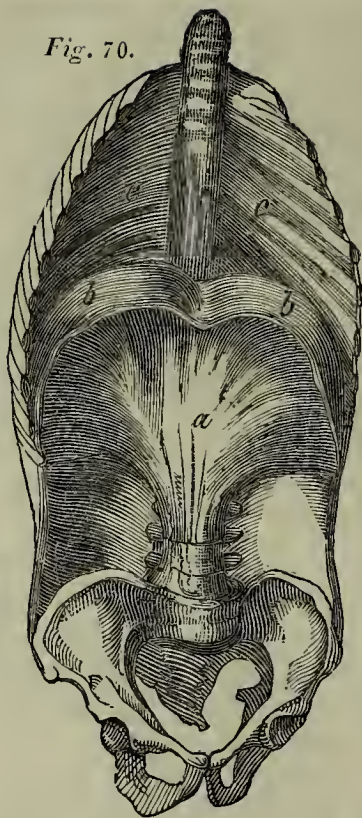
All the *muscles* which surround or are in any way connected with the bones which have been now described, do occasionally contribute in assisting the function of the lungs. Haller informs us that, while labouring under rheumatism of the large muscles of the chest, his respiration was difficult; and it must have been observed by every one, how the arms are fixed and the shoulders raised, when our object is to procure a very full inspiration. But the muscles more especially intended for respiratory organs are the *Serrati Postici*, *Triangularis Sterni*, *Intercostales*, and *Levatores Costarum*. The origins and insertions of these muscles a general reader would feel little interest in perusing, their actions only it is his business to understand. It may be sufficient, therefore, to observe that, with the exception of two,—one of the *Serrati* and the *Triangularis Sterni*,—all

these muscles are employed in elevating the ribs during the process of inspiration; so that nature might, at first sight, appear more anxious to provide an efficient inspiratory, than expiratory apparatus. But this is not really the fact. For when it is considered, that the natural condition of the chest is that which obtains after a full expiration, it will be obvious that the elasticity of the cartilages of the ribs and of the ligaments, which join them to the sternum and the spine, must form a powerful expiratory agent, and must tend, as soon as the muscles of inspiration have relaxed, to reduce the chest to its natural state. The bones, which form the walls of the chest, and the muscles, which cover these bones, may thus be regarded as antagonizing powers. The first are organs of expiration in virtue of their physical connections; the last are organs of inspiration in virtue of their specific action. When the ribs are permitted to follow their natural tendency they fall; but when the *intercostales* are allowed to act they rise. Natural position secures the one state, vital action the other.

There is still, however, another way in which the dimensions of the chest might be further modified. When the ribs are elevated, the distance between the spine and sternum is increased; when depressed, it is diminished; but we have as yet seen no mechanism which can alter its long diameter, which can either extend or abridge the distance between its base and apex. This brings us to the *Diaphragm* (*fig. 70, a*), a muscle of much greater importance than any yet described; which, being peculiar to the mammalia, distinguishes the respiration of that class from every other; and which is so situated as to divide the interior of the body into two parts—the chest and the abdomen.

The diaphragm is generally spoken of as composed of a central tendon and two muscles; the greater of which arises from the inside of the breastbone and cartilages of the false ribs, and the lesser from the vertebræ of the loins. But it is more simple to view it as a single muscle, which is fleshy at the circumference, and tendinous at the centre; as arising from the ribs above, and from the spine below; and as having the fibres issuing from these two origins inserted into a tendon, which, from its use and position, forms their common centre. This heart-shaped

Fig. 70.



The Diaphragm during Expiration. *a*, its tendinous centre; *b b*, its fleshy sides; *c c*, the lateral cavities of the chest, in which the lungs lie.

tendon gives passage to the inferior vena cava from the abdomen into the chest, and also to the œsophagus from the chest into the abdomen. It is firmly attached to the pericardium; so that the centre of the diaphragm being fixed, motion must be limited to its fleshy sides; and from the nature of their origin it may be inferred, that these muscular wings are concave towards the abdomen, and convex towards the chest.

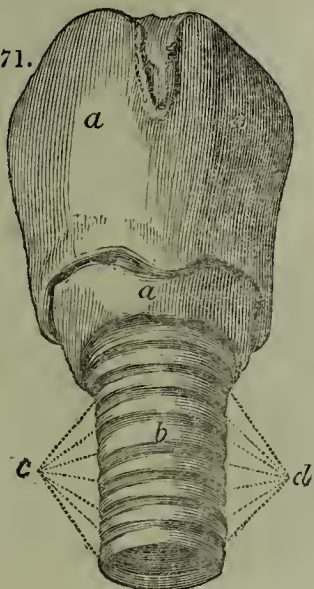
As it is by means of this muscle that respiration is principally conducted in man, everything has been done which the obliquity of its position, the nature of its attachments, and the mode of its construction could afford, to confer upon it the greatest range of motion with the least possible expenditure of space, or power. Why, may it be asked, should it not have been passed directly across the body from the sternum to the dorsal spine, in place of being made to slant from the loins to the sternum? Why should it be concave towards the

abdomen, and convex towards the chest? Why should it, in opposition to all other muscles, be tendinous in the centre, and fleshy at the circumference? And, finally, why should its sides be left free and floating, while its middle is firmly bound to the pericardium? Nature seldom shews any marks of peculiar design, without having some peculiar design in view; nor does she deviate from her general plan, without having something to accomplish which a particular arrangement only could effect. Had the diaphragm been passed directly across the body from the sternum to the spine, that is, had it assumed the form of a transverse plane, its motions could not have had such an influence upon the dimensions of the chest, as they have since it is placed obliquely. When it contracts during inspiration, a considerable portion of the abdomen is, as it were, thrown into the chest; and when it relaxes during expiration, a considerable portion of the chest is again made abdomen. But had the wings of the diaphragm been concave towards the chest, the space gained by their contraction would have been taken from the chest, and given to the abdomen; the very reverse of what was required. Again, had not the centre of the diaphragm been tendinous, the vena cava and œsophagus, which pass through it, must have been compressed whenever it contracted; and had not that centre been fixed, a muscle of such size and range of movement as the diaphragm, could not have worked with any certainty or effect. Besides, as the lungs are placed in the lateral cavities of the chest, and the heart occupies the centre, the lateral portions of the diaphragm only could influence the size of the respiratory organs; so that it had been, in one sense injurious, and in every sense useless to have endowed its centre with muscularity. The position of the diaphragm, therefore, is oblique to increase its range of motion; its sides are muscular to enable them to contract; concave towards the abdomen, that when contraction reduced them to a plane with the central tendon, the space then gained might be in favour of the chest; its centre is tendinous for the insertion of the muscular wings, to enable these wings to contract more forcibly, and to give a safe passage to the vena cava and œsophagus; and that centre is attached to the pericardium, that during the contraction of

the wings there may be a fixed point to give direction to their movements.

The *trachea*, or windpipe, is an almost cylindrical tube, composed of cartilaginous rings connected to each other by ligamentous substance, with which muscular fibres appear to be intermixed, and covered internally with a soft and vascular membrane, which secretes a mucous fluid to defend the surface of the canal from the acrimony of the air, (*fig. 71.*) For the accommodation of

Fig. 71.



Anterior View of Larynx and Trachea. *a, a, a*, anterior view of cartilages of larynx; *b*, trachea; *c, c, c*, cartilaginous rings of trachea; *d*, ligamentous and muscular portions of the trachea, by which the rings are connected.

the *œsophagus* or gullet, which lies immediately behind the trachea, (*fig. 72, e*) these cartilaginous hoops do not encompass the entire tube, but terminate posteriorly in a membrane, partly ligamentous and partly muscular, which, while it completes the trachea, admits of compression, and thus presents no inconvenience to the passage of the food along the *œsophagus* (*fig. 73.*)

On the top of the trachea is mounted the *larynx*, or musical part of the windpipe; which is composed of two portions—the *glottis* and *epiglottis*. The glottis is formed by the conjunction of four pieces of cartilage; *fig. 72, c, c, c*, represents a posterior view of these cartilages; and *fig. 71, a, a*, an anterior view of two of them, which are lined with the same mucous membrane that coated

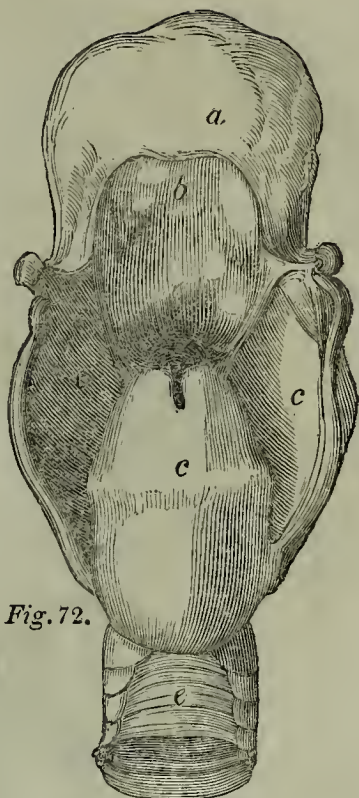


Fig. 72.

Posterior View of Tongue, Larynx, and Trachea. *a*, the tongue; *b*, the epiglottis; *c, c, c*, other cartilages of the larynx; *d*, opening into the cavity of the larynx; *e*, posterior portion of the trachea, which is not cartilaginous but membranous, consisting partly of ligament and partly of muscular fibre, in its natural situation in contact with the *œsophagus*.

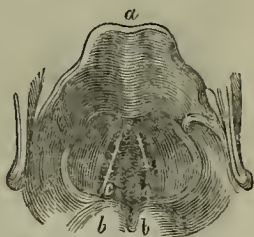


Fig. 73.

Represents the effect of the movement of the tongue backwards on the mechanism of the larynx, in the act of deglutition. *a, a*, the tongue; *b*, the morsel of food arrived at its back part or base, and already beginning to force down, *c*, the epiglottis, over the opening *d* into the glottis, and so closing the aperture.

the trachea, and are covered with small muscles which serve to move them. The epiglottis (*fig. 72, b*) consists of a single cartilage, which is situated above the other four, and, like the key of a flute, can close or open the *rima* of the glottis or longitudinal aperture through which the air passes into and from the lungs (*fig. 74.*)

Fig. 74.



c c c, margins of the glottis cut open and folded back; *b, b*, the vocal chords, in the site of the *rima glottidis*; *a*, the epiglottis.

After the trachea has descended the neck and entered the thorax, it divides into two parts, one of which goes to each lung. The ramifications which arise from these primary divisions of the windpipe are styled *bronchi*, and resemble exactly the air-tubes of insects both in construction and office. As these bronchi proceed they become smaller, and as they become smaller the cartilaginous rings of which they are composed become less distinct, until at length they entirely disappear; so that the air-cells, in which they ultimately end, appear to consist of nothing but an extension of the mucous membrane which had lined the bronchi.

The *lungs* (*fig. 75, bb*) are two spongy, conical bodies situated within the two lateral cavities of the chest, and separated from each other by the heart and a strong



Fig. 75.

The Lungs of Man.—*a*, the heart; *b b*, the lungs; *c c*, the diaphragm.

membranous partition (*fig. 75, a*). They are covered anteriorly by the ribs and sternum, behind by the spine, and their base rests upon the diaphragm, which separates them from the abdomen. In consequence of their containing air, from which they never can be cleared after birth, they are the lightest viscera in the body, floating upon the surface when placed in water. Their external aspect varies with their age. In infancy they are of a pale red, in youth of a darker colour, and in old age of a livid blue. They are distinguished into parts called *lobes*; and as the right side of the chest is larger than the left, because the heart is principally in the left side, the right lung possesses three lobes, while the left has only two. These lobes are composed of *lobules* connected by cellular substance, and

these lobules consist of an intermixed congeries of air-cells and blood-vessels. With the exception of a few nerves and lymphatics, which they have in common with every other organ, the lungs are entirely made up of air-cells, blood vessels, and cellular tissue. The last substance, which is the smallest in quantity, serves merely to connect the other two; and when it is entirely removed, after injecting the air-tubes and blood vessels with sealing-wax, the volume of the lungs is very triflingly diminished.

From the sketch which has been drawn of the comparative anatomy of respiration we have seen sufficient to prove, that what is principally required in the respiratory apparatus, is an organ so constructed as to allow the largest possible quantity of deterio-

rated blood to enjoy the fullest intercourse with the largest possible quantity of vital air. Such an organ is the grand desideratum of the function; every other is preparatory and subser-vient; and such a place of intercourse is met with in the human lungs. It has been supposed by Hales, that, representing the size of each air-cell at $\frac{1}{1000}$ th part of an inch in diameter, the amount of surface furnished by them collectively would be represented by 20,000 square inches. Keil has estimated the number of these cells at 174,418,615, and the surface which they present at 21,906 square inches; and Lieberkuhn has increased it to no less than 1500 cubic feet. It is upon these air-cells that the venous blood is distributed by an infinity of vessels derived from the pulmonary artery; it is for the sake of these air-cells that the lungs are formed, and the extensive respiratory machinery, which has been now described, is erected; it is during the circulation of the blood upon these air-cells that the desired alterations in its properties are wrought; and when the relative extent of the actual respiratory organ is compared with the insignificant dimensions of the lungs in which that organ is contained, it is difficult to conceive how so small a part, differently constructed, could be more effectually adapted to the objects which it is intended to accomplish. A stratum of blood, several hundred feet in surface, is exposed to a stratum of air still more extensive; and these two strata of contiguous fluids are comprehended within an organ, which may be easily compressed within the compass of a few inches. To look for any parallel to this amid the most masterly contrivances of science were vain.

Mechanism of Respiration.

THERE is as great variety in the *mechanism* as in the apparatus of respiration. Two classes of animals do not breathe in the same way, and different orders of the same class are not unfrequently distinguished by individual peculiarities. When the *frog* inspires he shuts his mouth, draws a quantity of air through his nostrils into the large membranous bag which is attached to his under jaw; this bag contracts, and the air which it contains is forced down into his lungs (*fig. 66.*) When the purposes of inspiration have been served, the muscles of the abdomen contract, his lungs are compressed, and expiration is per-

formed. This animal, therefore, swallows the air which he respire as he does the food which he digests; and the most effectual mode of suffocating him is to keep his mouth open.

When the *trout* respire it opens its mouth and takes in a quantity of water; the mouth is then shut and the inclosed water is forcibly driven among the vascular laminae of its gills. During the passage of the water through these fibrinated organs, the air which it contains exerts its purifying influence upon the blood, and, after accomplishing its object, it escapes beneath the large scales by which the gills are covered. In many worms and flat fishes the water, thus admitted by the mouth, is expelled through small holes situated in different parts of their body, but more especially in their sides. Fishes, therefore, cannot inspire air unmixed with water, nor can they inspire water unmixed with air. Air is necessary as the vitalizing principle of their blood, and water is necessary as a vehicle for the proper application of this principle to their blood vessels.

In *birds* the lungs are so nitched down between the ribs and perforated by air-holes, that they can neither expand as the chest enlarges, nor collapse as it falls. They preserve unalterably the same size. When the bird inspires his chest is elevated, a vacuum is formed within and air rushes into the lungs. But as it cannot remain in them, in consequence of the air-holes upon their surface, it passes out into the abdominal cells. Expiration now begins, the ribs fall, the air in these large air-cells is compressed, it again enters the air-holes, passes a second time through the lungs, and is expelled through the wind-pipe. The lungs of this class, consequently, contain a mere fraction of the air which they inspire, and during expiration they are compressed, not immediately by the ribs, but mediately through the air-cells which surround them.

In *man* respiration consists of a succession of alternate acts by which air is received into and removed from the lungs. When it is received the act is called *inspiration*; when expelled *expiration*. The one process depends upon the other. Air cannot be expired until it have been inspired, and a second inspiration cannot be made till the air already taken in have been expired. But, although these two processes are thus connected, one of them

is a much more vital action than the other. The lungs cannot be filled with air without a considerable effort on the part of many living agents; but they may be emptied of it in virtue of the physical construction of the respiratory system. A knowledge of this system is sufficient to prove that the natural state of the lungs is that of collapse. The ribs are jointed so obliquely to the vertebrae, and so connected anteriorly to the sternum, that a considerable force is necessary to bring them to right angles with the spine; that is, into a state prepared for inspiration. After death, therefore, when every living principle is extinct, and the body is allowed to fall into its natural attitude, the state of the chest is always that of expiration. The ribs are depressed, the diaphragm is pushed up into the thorax, and the lungs are confined within a cavity which expiration has diminished to the utmost.

It is obvious that as long as this state of parts continues, the entrance of air into the lungs is impracticable. But it is equally evident that, if by any means the chest could be enlarged and the lungs expanded, a vacuum would form within the thorax, the size of which would be proportional to the extent of this enlargement. Now, this actually occurs, and we have examined the machinery by which it is accomplished.

A short time, say one second and a half, after expiration, the muscles of inspiration begin to act. The intercostals contract, and by elevating the ribs increase the distance between the spine and sternum. The diaphragm descends as the ribs rise, and by pushing down the abdominal viscera allows the lungs greater freedom for expansion in that direction. Thus the cavity of the thorax is enlarged on all sides, and, since the lungs are quite passive during all these changes, diminishing when compressed and expanding when liberated, their dimensions must now be greatly enlarged, the air which they contain considerably rarefied, and a vacuum of some extent must be formed within their air-cells. But as air is an elastic fluid which seeks its own balance wherever situated, and as the air within the chest is rarer than that without, the consequence is that the denser or external air will, in virtue of its greater gravity, enter the trachea through the nostrils and mouth, and descending into the lungs occupy this newly-formed vacuum. This influx of denser air will continue until

the density of the internal be equal to that of the external air, when the act of inspiration is at an end. The intercostal muscles now relax, and allow the elasticity of the ribs, which had been hitherto counteracted by the contraction of these muscles, to restore them to their natural position. The diaphragm likewise relaxes, and allows the abdominal muscles to re-act and thrust it up into the cavity of the chest. The lungs are thus encroached upon in every direction; before by the ribs and sternum, behind by the ribs and spine, and below by the diaphragm. The newly-admitted air which they contain, being now no longer in a state of equilibrium with the external atmosphere, is forcibly expelled, and the chest is restored to the same condition in which we found it.

Such is the mechanism of respiration, as it obtains in a state of health, and the reader cannot fail to perceive how parts, the most distant and different in action, are made to co-operate to the production of the same effect.

In ordinary breathing we respire almost exclusively with the diaphragm, the motion of the ribs being scarcely perceptible. Dr. Jentz saw a man in Paris, who permitted an anvil, weighing 600 lbs., to be placed upon his chest while he lay in an horizontal posture, and a bar of iron to be beaten out upon it with weighty hammers, without discovering symptoms either of pain or uneasiness. But when, from debility or disease, the ordinary respiratory organs are insufficient, or when, from over-exercise or temporary excitement, the lungs require an unusual quantity of air, nature has several auxiliary resources in reserve.

If an inspiration only somewhat fuller than usual be desired, the *serrati levatores, triangulares, and pectoral muscles* are brought in to co-operate with the intercostals in elevating the ribs. But if the very fullest inspiration which can be taken be necessary, the bones forming the shoulder and shoulder-joints are firmly fixed by resting the hands upon the knees, and all the muscles, which have the slightest connexion with the chest either before or behind, are added to the inspiratory apparatus. At the same time, the abdominal muscles are relaxed to the utmost to facilitate the ascent of the ribs, and the diaphragm is, for the same reason, enabled to contract to the utmost to increase the long axis of the chest. In this way,

twice the usual quantity of air can be taken into the lungs at a single inspiration. But as the chest has been brought by this extraordinary effort into a very unnatural state, as all its ligaments and cartilages have been strained, and every neighbouring muscle has been pressed into its service and contracted to the utmost, it follows, that as soon as inspiration terminates there will be an increased tendency in the chest to resume its ordinary size—a tendency commensurate in degree with the force of the previous inspiratory effort. The farther the ribs were carried out of their natural direction the more certainly will they return to it when the forcing power has ceased to act, and this strong expiratory tendency on the part of the ribs is powerfully aided by the strong contraction of the abdominal muscles, which, by pressing the diaphragm far up into the chest, shortens the long axis of the thoracic cavity, as much as the falling of the ribs diminishes the short one.

The first Inspiration.

To a certain extent the respiratory apparatus is subject to the will. If a full inspiration be desired, we can call every inspiratory organ into action, and we can expand the chest to its utmost size; or, by forcing down the ribs and pushing up the diaphragm we can compress the lungs with unusual force, and expel from them a greater quantity of air than ordinary. But this controlling power which we possess is very limited, and the muscles of respiration are neither at all times obedient to the will, nor do they require the stimulus of the will to bring them into exercise.

When, by a forced inspiration, we have taken into our lungs the largest possible quantity of air, no mental effort can enable us to preserve the chest in that elevated state beyond a certain period. The intercostals will relax, the diaphragm will ascend, and the ribs will fall. Or when, by a forced expiration, we have expelled from the lungs the largest possible quantity of air, and have reduced the chest to its smallest size, inspiration soon commences even in opposition to the will, and, overcoming the elasticity of cartilages and the resistance of position, the ribs rise and liberate the lungs.

From the physical circumstances, with which the child before birth is surrounded, it is evident that respiration is incompatible with its economy. Ex-

cluded from air in a separate state, and enveloped in membranes filled with a watery fluid, the foetus, or unborn child, is virtually an aquatic animal, must be adapted to an aquatic life, and must be nourished with blood which comes to its system already purified for the purposes of life. To support a respiration of its own were consequently both impracticable and unnecessary. As long, therefore, as it is connected with its mother's system, its lungs cannot act through want of air, and its blood is arterialized without these organs; but the moment at which this connexion is dissolved by birth, the child is wholly cast upon its own resources, a double circulation is established, and respiration begins.

The first respiratory act appears to be purely mechanical, resulting from the change of position which the child undergoes at birth. By referring to the adjoining figure, which represents the child as it lies in the womb, it cannot escape remark, that everything has been



Fig. 76.

done which position could effect to diminish to the utmost the dimensions of the chest; and a little consideration must convince us that any change from this position, it matters not in what direction or to what degree, will have the effect of liberating the lungs from a portion of the pressure which they bear. The head cannot be raised from the breast, nor the knees removed from the abdomen, without straightening the spine, and the spine cannot be reduced to a straight line without elevating the ribs, and permitting the abdominal vis-

cera to fall; but the ribs cannot rise, nor the diaphragm descend, without enlarging the chest, and as the chest enlarges, the lungs, which are the most elastic organs of the body, will expand, their air-cells, which had been hitherto collapsed by external pressure, will assume an open form, and the external air will, in obedience to its own principles, go where it meets with the least resistance.

Connexion of the first Inspiration with the Establishment of a Double Circulation.

THE same cause which accounts for the first introduction of air into the chest, is likewise adequate to explain why the double circulation and respiration in the child are cotemporaneous in their commencement. The blood, which during foetal life had passed through the oval hole *e*, between the auricles, into the left side of the heart, and through the arterial duct into the aorta *f*, without visiting the lungs, is now solicited out of its ordinary path by the expansion of the chest.

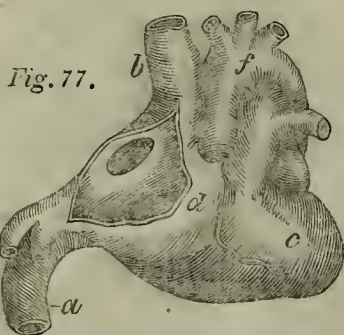


Fig. 77.

a, inferior vena cava; *b*, superior vena cava; *c*, right auricle; *e*, foramen ovale; *f*, aorta.

The same vacuum which forms within the lungs during this expansion, will draw blood through the pulmonary artery as forcibly as air through the wind-pipe. The arteries of the lungs will, therefore, fill with blood as their air-cells fill with air, and the moment the establishment of a double circulation requires that the child should purify its own blood is also the moment that respiration begins. Were not the lungs relieved from an unusual degree of pressure by birth, as we have endeavoured to prove, or did not something equivalent to this happen during that eventful period, to make the passage of the blood through the lungs easier than through the arterial duct and oval hole, we are left without a reason for the

sudden obliteration of these two foetal passages, and for the new and circuitous route taken by the venous blood at birth from the right to the left side of the heart. But, supposing that such a change obtains at the moment of birth, and that the air-tubes of the lungs and the arteries simultaneously expand, every difficulty vanishes. The blood will then find a more open passage through the pulmonary artery than through the aorta, the arterial duct being little required will gradually contract and ultimately close, the receipt of the left auricle equalling that of the right, the pressure against the opposite sides of the auricular partition will be equalized, the valve of the oval hole will be pressed up against the margins of this communicating aperture, and a perfect pulmonary circulation will be established. But, while these changes are going on within the sanguiferous system of the lungs, their pneumatic apparatus is at work; fresh air is drawn in at every inspiration, the passing current of deteriorated blood is subjected to its influence, and the common object of both functions,—the conversion of this vital fluid from a venous to an arterial state,—is effected by a common cause.

The beauty of this simple arrangement is very striking, and the indissoluble connexion between the action of the lungs and heart is remarkably displayed. As long as the blood of the foetus is purified by the mother, a single circulation is sufficient; but when birth cuts off the child from every adventitious aid, and casts it upon its own resources, its lungs, which had been hitherto inactive, are now called into operation, its blood is made to undertake a second journey to acquire those vital properties which formerly it had obtained elsewhere, and the same cause, which fills the blood-vessels of the lungs with blood, is employed to fill their air-tubes with air, prepared for its purification.

Effects of Respiration.

It may be inferred, then, that one of the first and most important effects of respiration is exerted on the circulating blood; but there is abundant evidence to show, that many other effects of no slight moment are accomplished by this function. The necessity of air for the support of animal life could scarcely escape observation in any age; but the ancients being ignorant both of the

constitution of the atmosphere, and of the alterations which the air experiences while in the lungs, could form no rational conjecture of the ends it serves in the economy; accordingly, there is no extravagance of the imagination in which they did not indulge. Without any further notice of these opinions, we shall go on to state what the uses of this function really are, as far as they are ascertained.

Effects of Respiration on the Chemistry of the Air inspired.

COMMON atmospheric air is composed of three gases, which are combined in different proportions, and are endowed with different properties. The most abundant of these is called *azote*, a term which signifies, 'incapable of supporting life;' the most useful is *oxygen*; and *carbonic acid* is the third, which amounts to little more than one per cent. of the whole.

For a long time it was believed, that upon the first of these gases—*azote*, respiration exerted little, if any, influence. It was regarded rather as a vehicle for the conveyance of oxygen to the lungs, than as a substance gifted with any intrinsic virtues. Subsequent observations have ascertained, however, that it disappears during respiration in considerable quantity: since some object must be contemplated by its removal, it is now generally considered that it acts some part in the economy of this function more efficient than that of affording a convenient vehicle for oxygen, although we are wholly ignorant of its real use. Sir H. Davy respired 18 cubic inches of common air during one minute. Before the experiment this air was found to contain 9.3, and after it only 4.1 cubic inches of azote, shewing that 5.2 cubic inches had disappeared. This experiment was variously repeated with the same result, and its accuracy has been subsequently confirmed by Dr. Henderson and others. Supposing, then, that 5 cubic inches of azote are consumed every minute by a moderately sized man, 22.464 grains will be expended in twenty-four hours.

Allen, Pepys, and Jurine, on the other hand, have endeavoured to prove, that azote is given out by the lungs during respiration, and their proof has been collected from many ingenious experiments; while Ellis has laboured to show, that respiration leaves the natu-

ral azote of the atmosphere untouched in quantity and unchanged in quality. The experiments of Spallanzani render it certain that reptiles absorb azote, and Humboldt and Provençal have ascertained that the same effect is produced upon inspired air by fishes. Admitting, however, that Davy's experiments are to be depended on, the quantity of azote consumed by respiration, when compared with its absolute amount, is so trifling, that one should think this gas must operate upon the well-being of life, in a way and to an extent that are not as yet understood. Out of 100 parts of common air, 77 consist of azote, 22 of oxygen, and 1 of carbonic acid; so that, supposing the alleged diminution of this gas to occur, the loss which it sustains within the lungs bears little proportion to its original quantity.

Oxygen, the second ingredient of the atmosphere, composes little more than one-fifth of the whole mass; yet, when frequently respired, it can be made entirely to disappear. If air be examined which the smallest insect has respired, the oxygen contained in it will be found diminished or consumed; if fishes be immersed in water which has been deprived of this gas by boiling, they languish and die. It matters not what element is inhabited, or what functions are performed; whether the animal breathe by lungs or gills; whether the air traverse every part of the body, or be confined to a single organ, oxygen is equally indispensable. It is this gas which renders the atmosphere essential to life; yet, when undiluted with azote, it cannot support continued respiration. When pure oxygen is inspired, a sense of warmth is felt in the chest, the heat of the skin is raised, the pulse is quickened, and other symptoms of excitement are produced. Lavoisier inspected the bodies of animals which had been for some time immersed in this gas; increased redness, unusual vascularity, and other indications of inordinate action, were discovered. Dumas states, that the lungs of a dog, which had been exposed to a similar trial, were even ulcerated. Pure oxygen appears, therefore, to be unfit for the maintenance of life; its dilution is requisite, and azote seems to be the appropriate diluent. We know that, in a separate state, azote is innocuous. Alone, it cannot be inspired; but it appears to be irrespirable only because destitute of oxygen, and

the proportions in which nature has compounded these aerial liquids, as they are met with in the atmosphere, are exactly those which render them most suitable for the economy of life. If the oxygen be diminished, the compound produces a sense of languor, and a tendency to sleep; if it be increased, the effect is stimulating. Mr. Ellis has stated, that the growth of vegetables is much injured when they are surrounded with too much oxygen; and it is equally certain that insects, if immersed in this gas in an unmixed state, die long before it is consumed. Saussure mentions a strong tendency to sleep as one of the sensations he experienced while traversing the summit of the Alps; but the accounts which some travellers give of the effects of elevated regions upon their respiratory organs may perhaps be more plausibly attributed to the increased rarity of the air, than to the diminished quantity of its oxygen. A small quantity of pure oxygen, indeed, will often support life longer than the same quantity of atmospheric air; but from its well-known tendency to excite, it may be inferred that its continued use would be injurious, if not fatal. Blumenbach procured three dogs of the same size: into the trachea of the first he inserted a pipe, which had attached to it a bladder, containing 20 cubic inches of oxygen;—after fourteen minutes the animal died. The bladder was then filled with atmospheric air, and its pipe was fixed into the windpipe of the second dog; in six minutes it expired. The air, which had been thus respired for six minutes, was made the subject of the next experiment on the third dog, which died four minutes after the introduction of the pipe.

The precise quantity of oxygen, which is necessary to support human life, it is not easy to calculate. Menzies states, that in twenty-four hours 51.840 cubic inches, or 17625.6 grains, are consumed by an ordinary man; Lavoisier raises the quantity destroyed in the same period to 46037.38 cubic inches, or 15661.66 grains; and the experiments of Davy lead to the conclusion, that 31.6 cubic inches are consumed every minute, making the quantity necessary for twenty-four hours 45.504 inches, or 15471.36 grains. From the trifling discrepancy between the last two results, it is probable that the quantity of oxygen, necessary for the maintenance of human

life during twenty-four hours, may range between 45 and 46,000 cubic inches, which, when weighed, make about 15,500 grains, or 2 lbs. 8 oz. troy. The variety, however, to which the consumption of this gas is exposed is very great. Scarcely during two hours in the day does the same person employ the same quantity. The nature and degree of his exercise, his condition of mind, his state of health, the kind of food he eats, the temperature of the air he breathes, and many other modifying causes, materially influence its consumption. When the hourly waste of oxygen, at the temperature of 54°, amounted to 1345 cubic inches; at 79°, it was found to fall to 1210: during digestion, more disappeared than when the stomach was empty, and less was required, as the quantity of vegetable food that had been taken was great. When the mind is tranquil and the body is at rest, comparatively little is necessary; active exercise and mental agitation require a more liberal supply. But where does all this oxygen go? For what purposes is it abstracted? To answer these questions we must inquire into the change which respiration effects upon the third gaseous constituent of the atmosphere—carbonic acid.

Unlike azote and oxygen, which are simple gases, *carbonic acid* is a compound of two substances, oxygen and carbon; and so incapable is it of supporting flame or life, that a taper is extinguished by being immersed in it, and it cannot, for even a moment, be inspired without causing a feeling of suffocation. Many experiments were performed upon this gas by the courageous Pilatre de Rozier. In one of these, he entered a brewer's tub during the fermentation of its contents, when carbonic acid was exhaled in clouds. A sensation of heat and itching was first experienced; this was speedily followed by difficult breathing, and a violent sense of suffocation; he could no longer distinguish objects; his face became purple, his limbs weak; he understood with difficulty what was said to him; and it was not until he had been again exposed for some time to pure air that these formidable symptoms were removed. Davy tried to inspire a mixture of two quarts of common air with three of this acid, without success; but, by increasing the proportion of common air to seven quarts, the mixture became respirable. When used in an undiluted

state, a burning sensation at the top of the uvula, and a violent feeling of suffocation, were complained of: giddiness and torpor were its effects when mixed with common air. It is not to be expected, therefore, that a gas of such deleterious properties should enter largely into the composition of a fluid so essential to life as atmospheric air; accordingly, it scarcely exceeds one percent., and it is probable, that even this quantity owes its presence more to chemical decomposition than original arrangement.

Let it be supposed that 100 parts of common air be respired by different animals, whose pulmonary habitudes are different, until they be no longer respirable even by an insect. It will be found that, in place of being composed of 77 azote, 22 oxygen, and 1 carbonic acid, they consist of 77 azote, and 23 carbonic acid. For the sake of round numbers, this statement is made general; but this point, like almost every other on the chemistry of respiration, is far from being settled; some maintaining that the oxygen lost is exactly replaced by the carbonic acid gained, while others assert that the carbonic acid added is less than the oxygen consumed. In ordinary respiration, however, air, which has only once visited the lungs, has not parted with all its oxygen. According to Dr. Goodwyn, a quantity of air taken into the lungs at a single inspiration, containing 80 parts of azote, 18 oxygen, and 2 carbonic acid, had its composition altered, after the experiment, into 80 azote, 5 oxygen, and 13 carbonic acid; 2 parts of the whole having entirely disappeared, and 11 parts of carbonic acid having been substituted for 13 parts of oxygen. Both classes of physiologists maintain that, whatever be the quantity of oxygen abstracted, the quantity of carbonic acid formed is nearly, if not altogether, an equivalent; and that this is the case whether the respired air be once or one hundred times inhaled. According to Menzies, $\frac{1}{20}$ th part of air which has been once respired, is carbonic acid, and his estimate of the quantity formed during 24 hours is 24105.6 grains troy; according to Lavoisier, it amounts to 17720.89; to Davy, to 17811.38 grains troy. From the great discordance which exists between the estimates of Lavoisier and Davy, when compared with that of Menzies, there is reason to believe that the computation of the last has been considerably overrated; yet, admitting it to be excessive,

those of the former are insufficient to account for all the oxygen consumed. Lavoisier supposed that 15661.66 grains of oxygen were expended in 24 hours; but 12924 are sufficient to form the 17720.89 grains of carbonic acid generated during the same period—leaving a residue of 2737.66 grains of oxygen unaccounted for. Again, Davy calculated that 15337 grains of oxygen were necessary for twenty-four hours' expenditure; but 12824.18 only are required for the formation of 17811.38 grains of carbonic acid during the same period, giving us an unexplained overplus of 2512.2 grains of oxygen. Now, as no subsequent experiments of any note can throw these conclusions into discredit, it may be concluded that the whole of the oxygen which respiration abstracts from the air is not accounted for by the carbonic acid which it generates—that some disappears without leaving behind any equivalent. What becomes of this residual oxygen it is difficult to say. Some believe that part of the watery vapour which is exhaled during expiration is occasioned by the union of a portion of the oxygen of the air with hydrogen extricated by the lungs from the blood; others assert that it is absorbed into the blood, and is lost in its course around the system; and it has likewise been said that the alleged deficiency depends upon the condensation which oxygen experiences by being converted into carbonic acid, and is, therefore, more apparent than real. That part of the vapour which is expired from the lungs may be the result of this union of oxygen with hydrogen, is probable; but when it is considered that upwards of 20 ounces of water are exhaled every twenty-four hours from the lungs of an ordinary man, it would seem reasonable to ascribe some of it to evaporation of the mucous secretion of the bronchi. The absorption of oxygen into the blood is a subject which will be hereafter entered on; and the supposed condensation of this gas, when it unites with carbon, stands unsupported by adequate proofs. It must be borne in mind, that the same causes which affect the consumption of oxygen have an equal influence upon the formation of carbonic acid, and that, therefore, every calculation which is made in the present state of this inquiry must be regarded only as an approximation to the truth. The investigations of Prout show that carbonic acid is exhaled in different quantities during different pe-

riods of the day ; and Tyfe has ascertained that its evaporation is much decreased by the use of wine, that it is reduced to almost one-half by vegetable food, and nearly to one-third by a course of mercury. According to Prout, it is generated in the greatest quantity about noon ; from one until eight in the afternoon its exhalation gradually decreases, when it remains at its minimum until three in the morning, after which it increases until twelve, when its maximum is attained ; so that general conclusions upon a point like this, when the experiments upon which they are founded may be disturbed by so many circumstances, cannot be much depended on.

Effects of Respiration on the Bulk of inspired Air.

THERE can be little doubt that the air which has been employed in respiration suffers some diminution in volume. Goodwyn supposed it to be reduced $\frac{1}{100}$ th in bulk. Abernethy, on the contrary, asserts that its volume, instead of being diminished, is increased. Sir H. Davy found that air which had passed through the lungs once only, suffered a diminution of from $\frac{1}{100}$ th to $\frac{1}{50}$ th, but that when it had been repeatedly respired, it lost $\frac{1}{8}$ th of its original bulk ; while Thomson is inclined to ascribe any trifling variation which may occur to accident during the experiment, or to its absorption by the lungs, independently of respiration.

An ordinary man, in a state of health, is found to take into his lungs, at an ordinary inspiration, about 40 cubic inches of air, all of which we may suppose he afterwards expels by an ordinary expiration. Menzies has proved, that after an ordinary expiration the lungs can be made to expel, by an increased effort, 70 cubic inches more ; and Goodwyn has calculated that 109 cubic inches still continue in these organs, after they have performed the very fullest expiration. So that the quantity of air contained within the chest after an ordinary expiration is $109 + 70$ cubic inches = 179 cubic inches, and, after an ordinary inspiration, $109 + 70 + 40 = 219$ cubic inches. But nothing can be more variable than such calculations. One man requires more air than another, and the same man will consume, under dissimilar circumstances, different quantities. As long as there are different pulmonary conditions in health and sickness, during ease and exercise, in

lungs differently proportioned, and in constitutions differently formed, the abstract fact, that one effect of respiration is to diminish the bulk of the air respired, may be considered certain ; but the precise amount of this decrease must remain undetermined.

Effects of Respiration on the Properties of the Blood.

HAVING seen that the oxygen of the atmosphere is essential to life ; that all airs are respirable only in proportion as it enters into their constitution ; that a great quantity of it disappears during respiration ; that it is replaced by an almost equal volume of carbonic acid ; and that the azote, with which in atmospheric air it is so largely intermixed, is more serviceable as a vehicle for its introduction to the lungs than for any intrinsic properties of its own ;—a question naturally arises, how is this oxygen converted into carbonic acid, and what effect has such conversion upon the properties of the blood ? We have seen that there are two different kinds of blood—venous and arterial ;—that venous is darker than arterial blood ; that the latter, during its circulation round the body, contracts noxious properties, upon which the dark colour of the former depends, and by which it becomes disqualified for the purposes of life ; that these noxious properties, and this dark colour, are abstracted from venous blood during its passage through the lungs ; and that one great object of respiration is to furnish the arteries with pure, nutritious fluid, by converting that which was contained in the veins into arterial blood. Now, although the precise mode in which this change is accomplished be still obscure, there is no question that the change does take place, and the general principles by which it is effected are ascertained.

It had been often remarked, that the blood of the right auricle was much darker than that of the left, and that the vermilion red of the latter seemed to be obtained during the passage of the blood through the lungs. It had been likewise noticed, as a singular occurrence, that the surface of blood which had been exposed to the air either became or continued red, while its under-surface remained black. This phenomenon was, however, explained away upon the principle of different specific gravities,—the black or weightier portion falling to the bottom, while the red or lighter portion

floated at the top; and it was not until the middle of the seventeenth century that the real action of the air upon the blood began to be perceived. By removing the surface of blood which had been for some time exposed to the air in an open vessel, Lower discovered that the new surface was soon converted into as bright a red as that possessed which he had previously removed; and to refute the opinion, that the different gravities of different portions of the blood furnished an explanation of this phenomenon, he inverted cakes of coagulated blood, exposing their black under-surfaces to the air,—when they also speedily assumed a florid hue. The conclusions countenanced by these observations were rendered still more unquestionable by subsequent experiments. Hewson injected air into the veins of a rabbit, by which its venous was changed into arterial blood; and Cigna, by placing blood within the vacuum of an air-pump, showed that the reason why its colour remained unchanged was its exclusion from the atmosphere.

Nevertheless, there was one circumstance which appeared, even to those who were otherwise satisfied with this explanation, exceedingly unaccountable. Even admitting that the florid colour of arterial blood depends upon the chemical action of inspired air, how can this air gain access to venous blood circulating within the substance of the lungs, seeing that the membranous sides of the air tubes as well as the membranous coats of the blood-vessels intervene? An experiment performed by Priestley completely removed this difficulty. "I took," says this philosopher, "a large quantity of black blood, and put it into a bladder moistened with a little serum, and, tying it very close, hung it in a free exposure to the air, though in a quiescent state, and the next day I found, upon examination, that all the lower surface of the blood which had been separated from the common air by the intervention of the bladder, and likewise a little serum, had acquired a coating of a florid red colour, and as thick, I believe, as it would have acquired if it had been immediately exposed to the open air; so that the membrane has been no impediment to the action of the air upon the blood." This experiment was repeated without previously moistening the bladder, and with the same result. Now, as it was found by Hales that the

membrane, of which the air-cells are composed, is only $\frac{1}{10000}$ th part of an inch in thickness, these experiments of Priestley were held decisive of the point, that the intervening membranes, which separate the air from the blood in the air-cells of the lungs, could not prevent these fluids from acting on each other. But two questions of interest still remained: how did the air, by coming into contact with venous blood, render it arterial?—and how did blood, once rendered arterial by such contact, again become venous? Before the time of Priestley, conjectures the most vague were entertained respecting the air's action upon the blood. One believed that it communicated to it a saline vapour; another, a volatile salt; while some maintained that the blood received nothing from the air, but that the air got something from the blood. But after this sagacious philosopher had revealed the composition of the atmosphere, and a better knowledge of the laws of life had displaced the crude doctrines of mere chemical and mathematical physiology, the real purposes of respiration became apparent, and the agency of the air upon the blood intelligible. Goodwyn enclosed a quantity of oxygen gas in a glass receiver, which he inverted over quicksilver, and then introduced into it four ounces of blood, which had been just drawn from the jugular vein of a sheep, when it instantly became florid. Atmospheric air was then substituted for oxygen, the colour of the blood was less speedily effected; and when carbonic acid was employed, its colour was changed to a dark purple. These experiments led to results of such interest, that their accuracy was at first questioned; but being carefully repeated and frequently varied, it came at length to be established as a fact, which at present all admit, that the constituent of atmospheric air which converts venous into arterial blood, is oxygen.

Theory of the Reciprocal Action of the Air and Blood.

By mixing arterial blood with carbonic acid, it is found to assume a venous hue; by mixing venous blood with oxygen gas, the arterial aspect is restored. The inference has just been stated, that the principle which renders arterial blood venous is carbonic acid, and that oxygen is the agent by which venous is converted into arterial blood. As

carbonic acid is composed of oxygen and carbon, and as it is certain that oxygen is the arterializing principle, it is obvious that carbon is the only part of this acid which can deteriorate the blood. It has been shown that the oxygen of inspired air is converted into carbonic acid during its stay in the air-cells; that the removal of carbon from venous blood renders it arterial; and that carbonic acid is composed of oxygen and carbon. It is a reasonable inference, that the carbonic acid expired from the lungs results from a union of the carbon of venous blood with the oxygen of inspired air. How or where this union is accomplished it is somewhat difficult to determine. Some suppose that the oxygen of the air attracts the carbon of the blood from the minute branches of the pulmonary artery, and that these elements unite in the air-cells; by others, it is maintained that the carbon of the blood attracts the oxygen from the air-cells, and that they unite in the blood vessels. In the one case, it is conjectured that carbon is exhaled from the blood into the air cells, where it meets with the oxygen of the inspired air, and is there converted into carbonic acid; in the other, it is argued that oxygen is inhaled from the air cells into the blood, where it meets with the carbon of venous blood, and is there converted into carbonic acid, which is thrown out into the air cells during the blood's passage through the lungs. Both doctrines have been espoused by men of equal talents, and many striking arguments have been adduced in support of each. The former boasts the names of Priestley, Lavoisier, and Crawford; the latter is maintained by La Grange, Davy, and Edwards. "It is well known," says Crawford, "that the blood undergoes a remarkable change of colour when circulating in a living animal; for the vivid arterial blood, in its passage through the capillaries to the venous system, acquires a deep and livid hue, and again resumes its light and florid colour in the lungs. Dr. Priestley has proved that similar alterations are produced in the colour of the blood by exposure to pure and inflammable (carbonic acid gas) air. Since, therefore, the arterial blood undergoes the same change of colour in the capillaries that it suffers by exposure to inflammable air; since it has an attraction to that fluid; and since the separation of inflammable air from animal substances is promoted by heat and by the tendency

of the juices to putrefaction, we may, I think, safely conclude that the change which the blood undergoes in the capillaries arises from its impregnation with this principle. And as the absorption of inflammable air, or its basis (carbon), is the cause of the change which is produced in the colour of the blood during its circulation through the capillaries, we may also conclude that when the blood again recovers its florid colour in the lungs, the inflammable principle is detached."

Although the general groundwork of this theory is considered sound, it assumes some points which are either false or insufficiently supported. It supposes that the blood does not receive its carbonizing principle until it reach the extreme capillaries of the aortic system. But Mr. Hunter has proved the contrary. Having exposed the carotid artery of a dog and passed two ligatures around it, at the distance of two inches from each other, he punctured the included vessel after the expiration of some hours, when dark-purple blood issued from the puncture; proving that arterial blood may be rendered venous without passing into either a capillary vessel or a vein. The same fact was shown by Hassenfratz. A number of glass tubes were filled with arterial blood, and hermetically sealed; the blood gradually began to change colour, and after some time became perfectly purple. It likewise supposes that the carbon of venous blood is attracted from the vessel which contains it by the oxygen of the air-cells; but many facts and appearances could be advanced decidedly favourable to another view. M. Vogel placed a quantity of venous blood within the receiver of an air-pump, and, having exhausted the receiver, a quantity of gas was seen to escape from the blood, which proved upon examination to be carbonic acid. But, as the existence of carbonic acid in the blood supposes the presence of oxygen, and as the lungs are the most likely organs through which this gas could gain entrance into the circulation, this experiment, which has been verified by Sir E. Home, must appear decisive as to the introduction of oxygen into the blood. The following experiment of Edwards is in support of the same view. He confined some frogs in hydrogen gas, and, by using certain precautions, succeeded in making them respire it for some time. When the hydrogen was examined after the

experiment, a quantity of carbonic acid, of nearly equal volume with that of the animals themselves, was found mixed with it. Some of the oxygen which formed this acid may have been within the air-cells of the frogs' lungs before the experiment; but the quantity of acid found after the experiment is incompatible with the supposition, that all the oxygen required for the formation of this acid could be derived from this source.

In the present treatise, however, it is impossible to enter into the merits of this controversy with a minuteness proportioned to its interest. We can only observe, that the theory of La Grange, which maintains that the venous blood, when it arrives at the lungs, absorbs a quantity of the oxygen contained within the air-cells; that this oxygen, during its circulation, combines with the accumulating carbon of the venous current, and forms carbonic acid; that this carbon may enter the circulation at any period of its progress; that by the time it arrives at the right side of the heart it has so increased, that the welfare of the system renders its expulsion necessary; and that with this view it is thrown out into the air-cells of the lungs in the form of carbonic acid;—is more consonant with common observation, more consistent in point of principle, explains the greatest number of difficulties, and is supported by the strongest facts. It explains how arterial blood may be rendered venous without leaving the arteries; how venous blood becomes darker as it approaches the lungs; how that oxygen is disposed of for which the carbonic acid does not account; how carbonic acid can be extricated from blood under the receiver of an air-pump, or exhaled by animals while respiring a gas which is destitute of oxygen; and how caloric is so evolved during the circulation of the blood, as to maintain every part of the body in a uniform degree of temperature.

Considering that the great object of respiration is to enable the carbon of venous blood to enter into chemical combination with the oxygen of the atmosphere, it must be admitted to be of little consequence whether the carbon unite with the oxygen in the air-cells, or in the blood-vessels. To bring about their union is the important point, and that they do unite is certain, from the disappearance of both—of carbon from venous blood, and of oxygen from inspired air; that they do

form by this union carbonic acid is also certain, from the fact, that this acid is generated in proportion as they disappear; and that the superior properties of arterial over venous blood must result from this union is established from the necessity of arterial blood for the purposes of life, and the necessity of oxygen for the formation of arterial blood. What part of the blood this oxygen acts upon, whether on the colouring matter, fibrin, albumen, or serum, is a question of curious interest, but of too abstruse a nature for discussion in the present place; and how the blood, during its circuit round the body, is so constantly and so largely supplied with carbon, is a subject of inquiry, which will come more aptly before us when we treat of the functions of the absorbent system.

Theory of Animal Heat.

WHILE considering the phenomena of life, it was observed that one of the most characteristic attributes of a living being is its faculty of resisting extremes of temperature. The porpoise, which lies buried beneath mountains of polar ice, is as warm as any of its own species which may be swimming beneath the Line; the Ethiopian, who scorches beneath a vertical sun, and the Laplander who is cradled in the snowy bosom of the North, enjoy the same degree of animal heat; man, wherever born, can go through the wide range of external temperature which lies between the freezing and the boiling points, without undergoing the slightest alteration in that of his own body. But a tendency to an equilibrium is a law to which caloric is uniformly obedient: there must be, therefore, a constant evolution of this substance from the surface of the human body, and a constant effort on the part of the surrounding atmosphere to reduce its temperature to a level with its own. Did this law operate on man without some countervailing influence, and were he, at the same time, subjected to the vicissitudes of temperature to which he is now obnoxious, his circulation would be interrupted or arrested; at one time his fluids would be congealed, at another evaporated, and the current of life would flow unequally, or would wholly cease. To avoid such consequences, a certain temperature is preserved, with an almost perfect uniformity, and in all animals it is somewhat above that of the medium in which

they live. The arrangement by which this uniformity of temperature is maintained is so perfect in itself, and so steady in its operation, that no ordinary degree of external heat or cold can materially affect it. It is true that a degree more or less may occasionally result from a sudden exposure to great vicissitudes; but such an elevation or depression, even when it does occur, is as trifling as it is transient.

This phenomenon was formerly resolved into an ultimate law in the animal economy; but it is now proper to endeavour to shew how animal heat is elaborated in the system, and by what physical means its uniformity is preserved. As soon as the general nature of respiration was understood, and its various conditions in different animals were discovered, two circumstances were observed to be invariable in their occurrence, and inseparable in their concurrence. It was found that all those animals which breathe have a temperature higher than that of the medium in which they live, and that this excess is strikingly proportional to the quantity of air respired. The temperature of the slug-worm, which breathes within the bowels of the earth, and the respiratory function of which must be necessarily so imperfect, is two or three degrees only above that of the clay which surrounds it; on the other hand, the heat of birds, which, of all animals, consume most air, is of all animals the greatest. When the temperature of the atmosphere was 56° , Mr. Hunter found that of the earth-worm to be $58^{\circ}5'$; while the thermometer rose to 140° when inserted into the body of the common fowl. Asthmatic patients, whose lungs either take in an insufficient quantity of air, or inefficiently act upon the air received, are, in general, some degrees cooler than such as have a healthy pulmonary system; birds, while in a state of torpor during winter, are nearly as cold as they are inert; and, in a word, so universal is this connexion between the generation of animal heat and the consumption of air, that the degree of perfection in which the respiratory apparatus exists in different animals is a certain index of their temperature, and their temperature of their respiratory function.

Striking as these facts appear, and obvious as the inference now seems to which they point, it was long before that inference was drawn. Corpuscular attraction, vascular friction, fermenta-

tion, and combustion, long occupied and obscured the minds of physiologists; and even when these vague conjectures had sunk into merited contempt—when, at length, it was clearly seen and generally acknowledged that there was a close and inseparable connexion between animal heat and respiration, still, the nature of that connexion remained wholly unknown. Assuming this relationship as established, Crawford had the great merit of founding upon it a theory, which for simplicity and beauty is scarcely to be exceeded by any that adorn the history of science. It is a general law, to which there appears to be no exception, that oxygen cannot combine with carbon without evolving heat: it is proved by experiment that venous blood has a less capacity for heat than arterial blood: when venous blood becomes arterial, its sensible heat remains unaffected, but its specific heat is increased, and therefore a constant supply of fresh caloric is required to maintain venous blood, of a given temperature, at the same temperature when it is converted into arterial. Now, it is maintained by Crawford, that this supply of fresh caloric is afforded in the lungs by the union of the oxygen of the air with the carbon of the blood; that the caloric generated by this chemical combination is entirely consumed in satisfying the increased capacity of arterial blood for heat; that, consequently, the temperature of the lungs is no greater than that of the heart, or of any other organ; that as the blood, arterialized in the lungs, in circulating through the body gradually becomes venous, its capacity for caloric diminishes; that as its capacity for caloric diminishes, heat is evolved; and that in this manner every part of the system is constantly maintained in an equal degree of temperature.

To the establishment of this ingenious theory, it is necessary only to prove two things: first, that oxygen cannot unite with carbon, to produce carbonic acid, without the evolution of heat; and secondly, that the capacity of arterial blood for heat is greater than that of venous blood. The establishment of the first point is essential, because it is necessary to explain the source of animal heat; while the proof of the second is equally indispensable to account for its uniform distribution.

The first point is universally admitted: for whether it be during combustion, fermentation, putrefaction, ger-

mination, or any other process in which carbonic acid is produced, heat is invariably given out, and the amount of carbonic acid formed is a tolerably accurate measure of this increase of temperature. But it has been proved that the lungs are manufactories of carbonic acid, and that the quantity of oxygen abstracted from respired air is replaced by very nearly the same quantity of this acid; therefore, when it is inferred that respiration, like combustion or fermentation, is a calorific process, the inference is not only supported by strong analogies, but grounded upon a steady and settled principle.

The second point is, perhaps, less certainly established. It is true that arterial blood is generally allowed to be one or two degrees warmer than venous blood; but when the great quantity of caloric, which the formation of so much carbonic acid within the lungs must evolve, is considered, this trifling elevation of temperature in arterial blood can be scarcely deemed sufficient to account for it. Some have considered this circumstance sufficient to overturn Crawford's theory, and certain experiments upon decapitated animals have encouraged others to maintain that animal heat is a secretion depending upon the brain and nerves. But the admitted facts that oxygen has a greater capacity for heat than carbonic acid; that carbonic acid is never generated without being accompanied by the evolution of caloric; that carbonic acid is found in profuse quantity during respiration, while an equal or greater quantity of oxygen is consumed; that young animals generate the least heat, while they use the least oxygen; that the temperature of hibernating animals is but a slight degree above the medium in which they live; that the temperature of all animals, whether hot or cold-blooded, is directly proportional to the quantity of oxygen inspired; and finally, that those very periods in the day, during which oxygen is inspired in greatest quantity, are the very periods when animal temperature attains its highest point;—all such facts (and they could be much extended) must be held strongly favourable to the inferences, that the union of the oxygen of the air with the carbon of the blood is necessarily productive of heat; that this union occurs during respiration; that the caloric formed by respiration is either almost or altogether expended in satisfying the increased capacity of arterial

blood for heat; that this latent heat of arterial blood is rendered sensible during the circulation by the gradual conversion of arterial into venous blood, and that when the blood has become as highly venalized as possible, and all its latent heat has become evolved, it receives a fresh quantity in the lungs during the combination of its carbon with the oxygen of inspired air*.

Subordinate Effects of Respiration.

THE purification of the blood and the generation of caloric are certainly the first and the most important effects of respiration; but beyond these there are many other objects which it serves. It is by it that we are capable of voice and speech; it is through it we derive the most valuable part of social intercourse; it is to it we owe the inestimable advantages that result from the communication of thought, and the exquisite pleasures that flow from harmonious vocal sounds, and from the still sweeter accents of affection.

It has been observed by Aristotle, that such animals only as possess lungs have a true voice; and this opinion the experience of modern naturalists confirms. It is true that many insects, and some other tribes of inferior beings, can emit certain sounds; but these sounds depend upon vibrations of the air, produced by the agitation of their external organs, and not upon any specific vocal mechanism.

Attempts have been made to ascertain how many varieties of tone the human voice is capable of emitting. Haller could articulate during one minute no fewer than 1500 letters; and as the articulation of each letter required the action of many muscles, several thousand distinct contractions and relaxations must have been performed in that period. Dr. Barclay observes, that, as the muscles of the larynx are at least seven pairs, fourteen muscles, which can act separately or in unison, are capable of producing 16,383 different movements, without bringing into the calculation the different degrees of force, or the infinitely varied order of succession

* While this theory of the generation of animal heat must be admitted to be highly ingenious and beautiful, experiments have been performed by Dr. Wilson Philip and others, from which it has been inferred that animal heat is a product of secretion; and that, like other secretions, it is very much under the influence of the nervous system. In this place we can only refer the reader to Dr. Philip's excellent treatise on the Vital Functions, both for the facts and the inferences.

in which they may be occasionally made to act. But in addition to these proper vocal muscles he enumerates fifteen other pairs, which are either employed in preserving the articulation of the larynx steady, or in regulating their general movements, as occasion may require. These fifteen pairs of muscles, when acting alone, are susceptible of 1,073,741,823 different combinations, and when co-operating with the succeeding seven pairs, give the following number, 17,592,186,044,415, as a gross estimate of the different varieties of movement which the different parts composing the human larynx are capable of producing. But each of these movements will elicit a distinct tone of voice; and when it is considered that each movement may be variously modified in intensity, and not only so, but that these several modifications of movement may be indefinitely combined, it is obvious that no limit can be ascribed to the range of the human voice, and that the varieties of its tones cannot be numbered.

Fœtal Substitute for Respiration.

If the lungs be organs of such vital influence that respiration is indispensable to life, that animals of the simplest construction require air, and that corporeal vigour and mental energy are intimately connected with the due arterialization of the blood, it may appear singular that the young of all animals, whether oviparous or viviparous, do not respire before birth, and that their blood experiences no alteration in their lungs. While the chick is enclosed within the egg, it possesses a sanguiferous system as minute as after incubation has been completed; its arteries carry red and its veins purple blood: and the fœtus, while in its mother's womb, is freely and faithfully supplied with this vital fluid in a purified state. During fetal life, secretion and absorption are regularly performed, nutritive matter is deposited, excrementitious particles are removed, and the blood experiences the same kind and amount of alteration during its journey round the system it supplies, as is witnessed after birth. How, then, is the noxious carbon, which is ever adulterating the vital current, abstracted from the blood?—where is oxygen procured to convert it into carbonic acid?—and if carbonic acid be formed, how is it expelled? In the incubated egg, this seems to be accomplished in the following way: the shell is ex-

ceedingly porous, and is internally in close contact with a very vascular membrane, which forms the external envelope of the contents of the egg. This membrane circulates more blood than is devoted to the body of the chick, and is separated at the greater end of the egg into two layers, which form a circular space, or bag, that is filled with air. This bag, or air-cell, is at first not more than a quarter of an inch in diameter, but as incubation proceeds it progressively enlarges, and towards the close of the process occupies a very considerable portion of the general cavity. Now, Spallanzani has ascertained that eggs freely absorb oxygen from the atmosphere, that the degree of this absorption is directly as the quantity of animal matter they contain, and that the air enclosed within these air-cells betrays a deficiency of oxygen and an excess of carbonic acid. It is, therefore, believed that the conversion of venous into arterial blood during incubation is accomplished by bringing the blood, as it deteriorates, to this vascular membrane which lines the shell, where it is purified by the air which enters through the pores with which the shell is permeated. This vascular membrane is equivalent to the minute ramifications of the pulmonary artery in man, and the porous shell is a counterpart to the walls of the air-cells of the human lungs. The former furnishes a sufficient surface whereon the venous blood may be spread, and the latter a convenient medium through which the oxygen of the external air may exert its peculiar influence upon this fluid. Air is as essential to the progress of an incubated egg, as to the existence of the chick after the shell is broken; and nothing more is necessary to arrest this process by suffocating the chick, than to exclude the external air by closing the pores of the shell with oil.

In the young of aquatic animals, various contrivances are employed to oxydate the blood in consistency with the medium they inhabit; and in the human fœtus, a vascular organ called *placenta*, which in office is similar to the lining membrane of the egg, is considered the fœtal substitute for respiration. This organ is principally composed of two distinct sets of blood-vessels, separated from each other by intervening cells. One set of these vessels is attached to the womb of the mother, and belongs to the mother's system; the other unites

to form the umbilical cord, and belongs to the system of the child. The vessels, therefore, which supply the child, and those which connect these vessels with the mother, are perfectly distinct. Injection poured into the one set will not pass into the other, and the communication which they enjoy is maintained only through the interposition of cellular cavities. Now, it is within these cellular cavities that the work of oxydation is supposed to go on; but, whether these cells possess the prerogative of absorbing carbon from the foetal vessels which lie on one side of them, and oxygen from the maternal vessels which ramify on the other, or whether of themselves they exert some change upon venous blood equivalent to oxydation, is at present unknown. Argument may be used in support of either view; but the investigation is so incomplete, that it would be vain to attempt to anticipate the result, which careful experiment and diligent research can alone obtain. One circumstance only is known with certainty, that the blood which the child sends to these cells is venous, that the blood which it receives from them is arterial, and that the alterations which the lungs are destined to work upon this fluid after birth are effected, during foetal life, by, or at least through the placenta.

Having now concluded our description of the three great functions of life—digestion, circulation, and respiration; having shown how the food is converted into blood, how the blood is circulated through the body, how the noxious qualities with which it becomes tainted during its journey are removed, and its purity maintained, it will be necessary to consider the ultimate design of such an elaborate system, to investigate the reason why blood must be so freely supplied by the stomach, so constantly circulated by the heart, and so regularly purified by the lungs. And this brings us to the subject of secretion.

Secretion.

At no period of life is the human body perfectly complete. At birth the process of development is still unfinished; during infancy every organ is weak, and every function is imperfect; at the period of puberty, parts previously unexercised suddenly enlarge, and take on new actions: manhood, requiring in the discharge of its offices the utmost ex-

tent of power, brings every resource of the system into full operation; while, in old age, functions no longer necessary are gradually withdrawn, and organs which have ceased to discharge duties no more required insensibly decay.

The machinery by which this reparative system is conducted is extensive and complex. Nutritive matter taken into the stomach is there converted, as we have seen, into chyle; chyle is converted by the lungs into blood; blood is carried to every part of the system, and in every part of the system is changed into those substances which are necessary either for its growth or reparation. Wherever muscle is required, muscular fibre is deposited; where bone is needed, ossific particles are laid down in the requisite form and in the desired order; where it is necessary to construct cellular tissue, or to deposit fat, albuminous and oily matter are provided. The process by which these different substances are eliminated from the blood is termed *secretion*; that by which they are removed when no longer useful is called *absorption*: the result of both actions combined is denominated *nutrition*. The first process is preparatory to the second, and both are essential to the third. Were the old particles not regularly removed, new particles could not be regularly deposited; and were not fresh nutritive matter ready for deposition as absorption proceeds, emaciation would be the first, and death the ultimate and the speedy result.

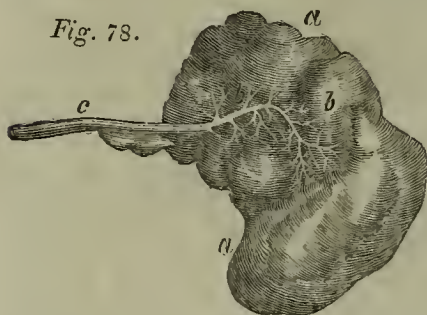
How the chyme is elaborated in the stomach by the gastric juice, how the chyme is converted into chyle in the duodenum, how the chyle is arterialized in the lungs by the action of the air, and how the arterialized blood is transmitted by the blood-vessels to every organ in the body, have been already shown; but it still remains to be explained how this common fluid, which exhibits the same properties in every part of the circulation, can be converted into bone and brain, into muscle and membrane, into cartilage and fat; how saliva and bile, how urine and mucus—fluids the most active and the most insipid—can be manufactured in determinate quantities, in certain textures, and at appropriate periods, out of a bland material totally unlike any and every substance which it generates!

Organs of Secretion.

THE apparatus by which the animal se-

cretions are formed assumes a thousand modifications of external aspect. Sometimes nothing can be discerned but a smooth vascular membrane, such as the pleura which lines the chest, or the pe-

Fig. 78.



A gland with an excretory duct, *aa* the substance of the gland irregular and lobulated; *bb* the small branches by which the excretory duct rises from the gland; *c* the trunk of the excretory duct fully formed.

ritoneum which envelops the viscera of the abdomen. At another time this membrane is not smooth, but rough, and covered with small vascular elevations, called *villi*, giving to this entire surface a velvety appearance. In one organ the secreting membrane assumes the form of small bags, called *follicles*, which contain an aperture in their centre for the transmission of the substance secreted by their internal surface. In another it constitutes sacs, open at one end, denominated *lacunæ*, which are sometimes single, as in the nose—sometimes ramified, as in the neck of the womb. Again, the wax which defends the passage to the internal ear seems to be secreted by small membranous cavities, which open, by means of small ducts, upon the surface of the auditory canal; while the oily matter which is formed beneath the cuticle, more especially in the armpits and groins, appears to be a secretion produced by bodies similarly constructed, and of the same figure. These small secreting bags are known by the name of *glands*, and the small tubes through which they convey the secretions they elaborate are styled *excretory ducts*. But different as the external characters of all these secreting organs may be, yet their general structure is essentially the same; and the more carefully the secreting apparatus is examined, the more convincing will appear the reason for believing that every external modification of structure has been adopted for the sake of convenience rather than be-

cause it was indispensable: nothing appears absolutely necessary to the performance of secretion, save capillary blood-vessel. The chain of connexion between the simplest secreting surface and the most complex gland, of which only the first links have been now given, might be easily completed, by tracing the gradual complication of an elementary secreting organ, as it appears in a serous membrane, up to the most elaborate specimen of glandular structure.

When a bone is broken, blood is poured out into the fracture, and there coagulates. After a short period, vessels are seen to shoot into this coagulated blood, the blood gradually disappears, and gelatinous matter occupies its place. This gelatinous matter progressively hardens, osseous particles are slowly deposited, and thus the fracture is ultimately repaired. During all these stages of renovation one agent appears to be principally employed, and that agent is capillary blood-vessel. It is capillary vessel which shoots into the coagulated blood, which deposits the callus, which conveys the osseous substance, and which unites the fractured bone. When muscle is divided the same process is established, excepting that fibrin is deposited instead of ossification; and whether the secretion be nerve or cartilage, tendon or skin, no difference can be detected in the secreting vessel, and nothing essential but secreting vessel can be discovered.

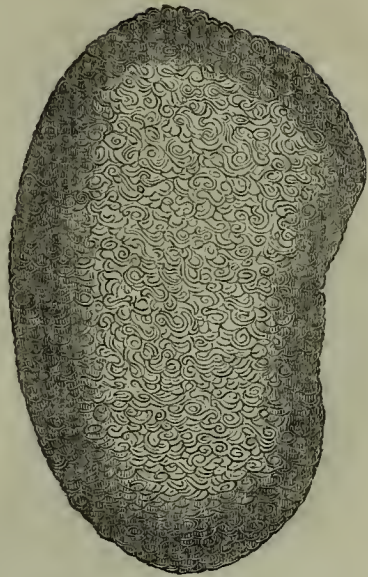
If, then, nothing but capillary blood vessel be required to secrete such important and different substances as the animal solids, may it not be suspected that the fluids of the human body are formed in the same way, and by the same instruments? The mucus which lubricates the nostrils is secreted by a fine and highly vascular membrane which covers them internally. The perspiration which oozes from the skin is poured out through small apertures in the walls of capillary arteries, which lie beneath the cuticle. The water which exudes from such serous membranes as the pleura, which lines the chest, or the pericardium, which surrounds the heart seems to be filtered in the same manner through these vascular strainers from the general mass of blood. In none of all these, and in no analogous instance can there be found any specific secreting apparatus. Capillary blood-vessel alone discoverable.

Malpighi maintained that such gland

as the liver are composed of very small bodies, called *acini* from their resemblance to the stones of grapes; that these acini are hollow internally, and externally covered with a net-work of blood-vessels; that these minute blood-vessels covering the acini pour into the cavities of these elementary cells the secreted fluid as it is eliminated by them, out of which it is afterwards removed by ducts. The minute dissections of Ruysch, however, induced this distinguished anatomist to dissent from the views of Malpighi; and, after a series of very accurate experiments, he was satisfied that the apparently hollow acini of Malpighi are merely convoluted vessels, perfectly continuous with the excretory ducts that carry away the secreted substances. This opinion was, for a time, strongly opposed; but it afterwards became general, and is now, perhaps, universally adopted.

The chief, if not the only, difference between the secreting structure of glands and that of simple surfaces appears, then, to consist in the different number and the different arrangement of their capillary vessels. The actual secreting organ is in both cases the same—capillary blood-vessel; and it is uncertain whether either its peculiar arrangement, or greater extent in glandular texture, be productive of any other effect than that of furnishing the largest quantity of blood-vessel within the smallest space. Thus convoluted and packed up, secreting organ can be procured to any amount that may be required, without the inconveniences of weight and bulk. These acini are most distinctly seen in the liver and spleen; in the pancreas and kidneys they are less perceptible; and in the prostate and tonsils they cannot be detected by the finest glasses. Glandular structure has accordingly been arranged into three varieties. In the first are placed all those glands which are uniform in their external surface; which are composed internally of acini, bound together by cellular tissue, and which are enclosed in a general membrane. The *liver* affords a good illustration of this form of gland. In whatever part it may be examined, its texture appears uniformly the same. Nothing but acini can be seen—there are no larger and no smaller subdivisions; and when the structure of one acinus has been fully ascertained, the composition of the entire organ is understood. The anatomy of the second variety is somewhat dif-

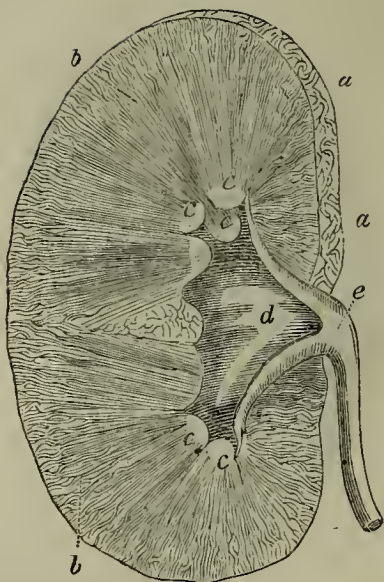
Fig. 79.



This figure represents the human kidney, which is so finely injected, that what were considered acini or hollow globules by Malpighi, appear to be merely convoluted vessels.

ferent. The glands pertaining to this order are obviously composed of subordinate divisions called *lobes*, which themselves consist of subdivisions called *lobules*; these lobules are formed of smaller bodies, which are again divisible into bodies still smaller, until we ultimately arrive at the elementary acini, which are, in common with the first class of glands, the rudimental constituents of the second class. As a fine example of this glandular tissue, the *kidney* may be taken. When viewed externally, it is manifestly lobulated, and its internal structure is strikingly beautiful. It consists of two distinct varieties of texture, —the first, being external, is called *cortical*, and the second, from its office, is denominated *tubular*. The cortical portion is the secreting organ of the kidney; the tubular portion is mainly composed of tubes, which convey the urine formed within the cortical tissue into the reservoir, or *pelvis*, of the kidney. These tubes are at first, where they issue from the cortical substance, very small and numerous; but they increase by uniting as they proceed, and they form considerable trunks before they terminate in the small oval projections called *papillæ*, *ccc*. These papillæ, which are formed by the union of the uriferous tubes, project into, and are surrounded by membranous cups called

Fig. 80.



The interior of the human kidney: *a a*, the cortical portion; *b b*, the tubular portion; *c c c c*, the papillæ; *d*, the pelvis; *e*, the ureter.

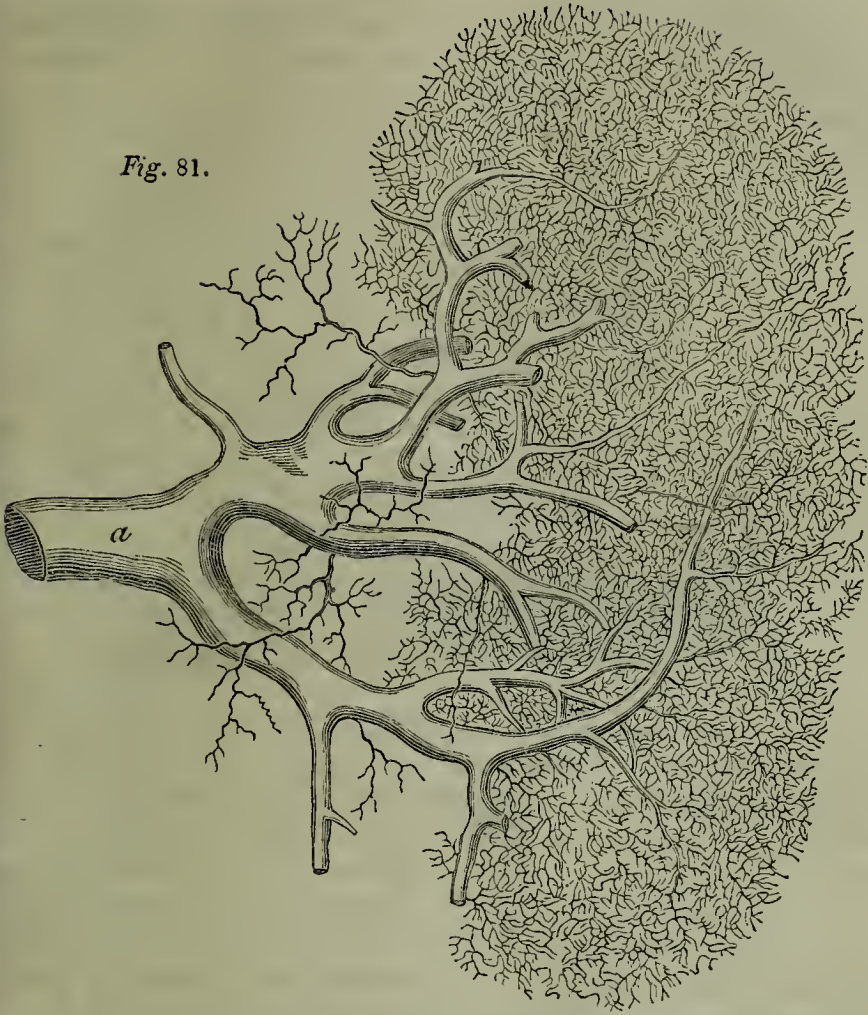
calyces, which receive the urine poured out by the papillæ from the extremities of the tubes, and convey it onwards to the pelvis or basin of the kidney, from which it is conducted by an excretory duct, styled *ureter*, into the urinary bladder.

The two varieties of glands now described, differ only in the number of their component parts, not in the nature of their composition; and, because the first form of gland consists of parts of the same size and equally elementary, while the second divides and subdivides before its rudimental structure is attained, the former is generally termed a *conglomerate*, the latter a *conglobate* gland.

The third and last form of gland is distinguished from the two preceding in having no discoverable specific structure. Without lobes, lobules, or acini, these organs exhibit neither parts nor divisions; they are dense, firm, lacerated with difficulty, and present everywhere a striking uniformity of aspect. Still they are highly vascular, and, when inflamed, produce excruciating pain; so that, in whatever other points these different forms of glandular structure may disagree, they are all equally remarkable for the profusion of blood-vessels with which they are supplied. It has been estimated that the glandular portion of the human body contains two-thirds of

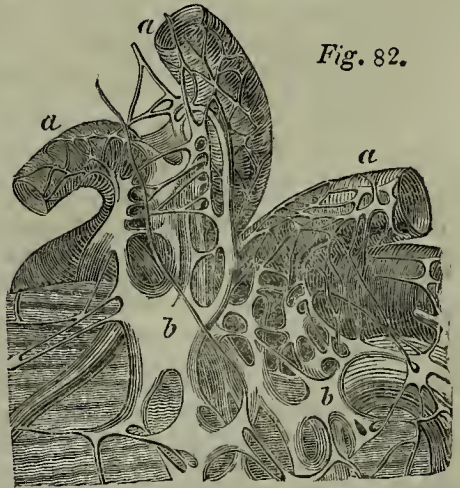
the entire mass of blood; and when successful injection has rendered all their vessels visible, six-eighths of their whole structure appear to be composed of capillary blood-vessels, for secreting the fluid which they are destined to elaborate, and of excretory ducts for removing that fluid as it forms. When all these facts are compared and considered, it would seem a reasonable inference that, as far as regards the vascular part of the apparatus, to constitute a secreting organ, blood-vessel alone is requisite; and that glands differ from mere secreting surfaces, as the pleura or peritoneum, chiefly in having a greater number of blood-vessels, only differently arranged. The intervening cellular tissue, by which these blood-vessels are tied up and connected, appears not to be essential, because in a mere serous membrane there is little or no such cellular tissue; nor are excretory ducts indispensable, since many glands have central apertures instead of ducts, through which their secretions are poured out. In the present imperfect state of our knowledge, it is impossible to estimate what effect difference of size, length, and direction in the secreting vessels, may exert upon the nature and quantity of the substance secreted. It is reasonable to believe that these circumstances may exert, and that they do exert, considerable influence upon the process; but, as far as regards the vascular part of the apparatus of secretion, all that is really known is told when it is stated, that wherever this function is performed, there is provided an abundant supply of capillary blood-vessels.

To the blood-vessels of secreting organs, as to all other parts of the body, are added nerves; and the number of nerves which are distributed to secreting organs, bears a close relation to the number of blood-vessels. If the capillary arteries are countless, so also are the ultimate nervous filaments. Moreover, there are some anatomical peculiarities in the nerves of secreting organs, which deserve to be borne in mind, because it is probable that they are intimately connected with the function of secretion. While treating of the nervous tissue, it was stated that in all the more perfectly organized animals the nervous substance is disposed in four different modes, forming four distinct parts or organs—nerves, ganglia, or appendages to particular nerves, spinal cord, and brain. With one exception,

Fig. 81.

a the splenic artery, separating into a rich variety of branches, which divide and subdivide into a number and minuteness so extraordinary, that the spleen, the gland which this artery supplies, seems to be almost entirely composed of blood-vessels.

no nerve that comes off from the brain possesses a ganglion; but every nerve that issues from the spinal cord, is provided with one or more of these knot-like bodies. What object the ganglia serve is not understood; but we know that the nerves of sensation consist of one set of filaments, that the nerves of motion consist of another set of filaments perfectly distinct from the former, and that the nerves of secretion consist of these ganglionic nerves. These ganglionic nerves are destitute of feeling, the occasional sensibility which they indicate being, probably, derived from the nerves of sensation with which they intermingle and communicate; and they are not obedient to the will. As soon as they issue from the ganglia, they proceed to the trunks of the secreting arteries,

Fig. 82.

a a, blood-vessels; *b b*, a rich network of nerves investing the external coat of the blood-vessels.

which they invest as with a tunic, and upon the branches of which they are completely spent. That this most inti-

mate and peculiar connexion between the ganglionic nerve and the secreting artery should exist, without functional in-

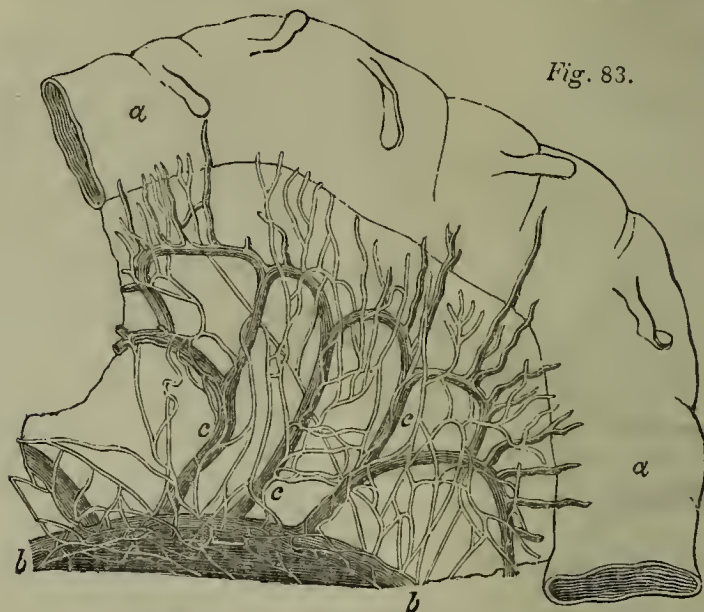


Fig. 83.

a a, a portion of intestine; *b b*, part of the abdominal aorta; *c c c*, nerves following the course of the branches sent off by the aorta to supply the intestine.

fluence being communicated to the vessel by the nerve, is scarcely to be conceived. What that influence is, it is impossible to say; its extent will presently be pointed out.

Substances secreted.

CONSIDERING, then, the great simplicity of the secreting organ, and the general sameness of the blood from which every secretion is derived, it is remarkable that so many solids, so differently constituted, and such a variety of fluids, so totally dissimilar both in property and aspect, should be manufactured out of one common material, and by one common apparatus. Nothing exists within the vegetable or animal kingdom but secreted substance; and whether we look to the meanest shrub, or to the noblest animal, the most splendid variety of substance and of quality is observed. In the one kingdom we find flowers of the gaudiest colours, sweets of the most delicious taste, odours of the most captivating fragrance,—all formed out of a simple and almost insipid sap; and in the other we discover bones hard and insensible, muscles soft and contractile, nerves tender and irritable, fluids insipid, sour, bland, and acrid, juices the most agreeable, and poisons the most pernicious—all proceeding from one com-

mon fluid. Much of the food which we eat, of the dress which we wear, and of the houses which we inhabit, is derived from this source. Even light and heat, electricity and galvanism—substances the most subtle and mysterious, can be elaborated by secretion. The electrical properties of the *Torpedo* are too well known to require description. The *Ela-ter noctilucus* shines so strongly, that many Indian tribes in South America were, at one period, said to have employed no other light for business than that which these insects emitted; and even now it is customary for their women to wear them as brilliants in their hair. The light evolved by the *Medusa pellucens* is occasionally so vivid, that water, in which these animals have been for some time confined, appears, when poured out, like a stream of fire, or of melted gold; and Spallanzani describes an individual of the same species as quite visible, by its own light, when thirty feet below the surface of water. The *Pyrosoma Atlanticum* is an elongated fish, which, when floating upon the surface of the ocean, resembles a bar of incandescent iron; and the *Pennatula phosphorea* emits light so copiously, that fishermen, while at work, are said to have availed themselves of its direction. Most of our finest dyes and of our

ctive medicines are animal secretions. The Tyrian purple, so celebrated among the ancients, is now known to have been obtained from different species of the *Gasteropoda*; the Romans employed the black fluid secreted by the cuttlefish as an ink; the Indian ink, which comes to us from China, is supposed to be the secretion of some *Sepia*; and the colour called *Sepia* by painters, is the inky fluid of this animal reduced to dryness. *Musk* is a secretion of the *Thibet musk*; *Castor* is obtained from a species of *Beaver*; and for *Civet* we are indebted to the *Civet-cat*.

On a former occasion, some account was given of the different solids and fluids which enter into the composition of the human body. It was then observed that, however dissimilar the former might appear, they could be arranged into three distinct classes—into cellular, muscular, and nervous solids; and that, perhaps, the least objectionable classification of the latter was into aqueous, albuminous, mucous, gelatinous, fibrinous, oleaginous, resinous, and saline fluids. The general physical and vital properties of each solid were likewise stated; the different organs into the composition of which each entered were enumerated; and the uses to which each was applicable were briefly described.

It has been usual to restrict the term Secretion to the animal fluids, but there is no reason why it should not also be applied to the solids. Bone and muscle, tendon and skin, are as different from the general mass of blood, and are as dependent upon it for their formation, as bile or mucus, tears or saliva. The secretion of urine is as essential to nutrition as that of blood-vessel, or nerve; for, although this fluid is separated from the blood in order to be expelled, while blood-vessel and nerve are separated in order to be retained, yet, did the separation of urine cease, the blood would be no longer fitted for the purposes of life, and neither nerve nor blood-vessel could any longer be deposited.

Chyme, chyle, and blood, by far the most important fluids of the body, because the source of all the rest, have been already sufficiently described; and as many of those which proceed from them have nothing interesting beyond the theory of their formation, it will not be necessary to give any further account of them here.

Theory of Secretion.

THE secreting organ is so simple and so uniform, the secreted substances are so dissimilar, and the blood, upon which the former operates, and from which the latter are produced, is so much alike in every part of the body, that there is little apparent correspondence between the secreting instrument and its action. Were glandular texture indispensable to secretion, and were the qualities of the secreted substances invariably connected with obvious peculiarities in the texture of the secreting organs, it might be hoped that structure would discover a key to their function. But when it is found that bodies evidently glandular, like the spleen, brain, thyroid, and lymphatic glands, eliminate no visible secretion; that glands anatomically similar elaborate secretions most opposite in character; that, while simple fluids are sometimes formed by glands, complex fluids are frequently formed without them; that, in fine, there are glands without secretions, and secretions without glands; it follows that gland and secretion can have no inseparable connexion; and that it is vain to hope to explain, by mere peculiarities of structure, either the general theory of secretion, or the individual varieties of the different secretions.

At the same time it is reasonable to believe, that structure does exert some influence on secretion. The vessels of each secreting organ differ in number and size, and they may likewise differ in direction and arrangement. The same remark is equally applicable to their nerves; and though, in the present state of our knowledge, we are unable to determine what influence such anatomical diversities may have upon secretion, that some influence is derived from them is well established. All animal secretions are formed from the blood, and, with the exception of the bile, from arterial blood; and although the blood, as has been shown, does not contain all the proximate principles that are to be detected in the animal secretions, it does contain the four elementary principles that have been described as entering into the composition of animal matter. Now, it is the object of secretion to combine and recombine these elementary principles in such different proportions as to form out of them the different substances which either the

growth or the nutrition of the body may require; and it is not improbable that one effect of structure is to bring the blood into circumstances favourable to such decompositions and such new arrangements. It is certain that two circumstances, most essential to chemical action, are, the minute division of the substances to be acted on, and the close approximation of their integrant particles. But one great aim of all the secreting organs, whether they be simple surfaces, complex glands, or in whatever mode they may be varied, seems to be to bring about this minute division, and this close approximation, of the particles of the blood which they contain. Hence the astonishing minuteness of the secreting arteries, and hence their endless inosculations with each other. It has further been conjectured, that in every secreting organ these minute vessels differ in the angles at which they go off from the trunk, in the course which they pursue through the glands, and in their length and size; that these differences materially affect chemical action; and that, probably, both the generation and transmission of the galvanic fluid, the agency of which in dissolving old, and in establishing new combinations is so remarkable, may partly depend upon them. These considerations, taken collectively, may, perhaps, afford us some assistance in conceiving how structure may minister to the performance of secretion, how apparently trifling variations in the secreting organ may produce most important changes in its results, how new affinities may be brought into operation, how new combinations may be formed, how new substances may be generated, and how these substances may differ from each other as much as they differ from the common fluid out of which they spring. Prout has shown that *urea* is composed of two atoms hydrogen, one atom oxygen, and one carbon; but by removing one of the atoms of hydrogen, the *urea* is converted into sugar; and by adding another atom of carbon, lithic acid is produced. Mucus, which is the characteristic ingredient of mucous secretion, seems to be albumen in a coagulated state. Gelatin, which is the peculiar animal matter contained in gelatinous secretions, may be formed from albumen, by digesting the latter in diluted nitric acid. Oily matter may be manufactured out of fibrin by the addition of

a little oxygen, and the red particles of the blood may be converted into bile by the same process. It cannot, therefore, be denied that secretion is in part a chemical process, and that to the varying combinations and proportions of the elementary principles of the blood may be clearly traced many of the substances which are extracted from it. Still it must not be forgotten that unaided chemistry is very limited in its influence; and that some other agent must be looked for, by which these chemical operations are regulated, by which affinities are arranged, and results are determined. There is some elective principle which selects out of the general mass of blood such substances as each secreting organ stands in need of, which sends these substances to the appropriate organ, which determines the quantity sent, and which consults the periods when supply is necessary. This presiding principle is life. When the albumen of the blood is coagulated and converted into membrane, or when its fibrin is oxydated and transformed into fat, the change, in both instances, may be immediately chemical, but, remotely, it is vital.

The liver cannot secrete bile unless the elementary principles of bile be contained in the blood which it receives; and, in a chemical point of view, it is unimportant whether these principles exist in the blood generally, or only in that portion of it which supplies the liver. If they exist in the general mass of blood, it is the principle of life which determines their separation in the liver, rather than in the lungs or in the kidneys; and if they be contained exclusively by the blood devoted to the liver, it is life to which this exclusive appropriation is to be ascribed.

It is more than probable that the instrument by which this vital principle is brought to bear upon the secreting apparatus, is the nervous system: hence the close connexion which it has been seen is maintained between the capillary blood-vessel and the ultimate nervous filament. That the nervous system is the communicating medium through which life operates upon secretion, is favoured by various phenomena, and is still more strongly supported by direct experiments. Grief relieves itself by a flow of tears; hunger encourages the secretion of gastric juice; and melancholy is proverbial for accumulating bile. During the operation of

fear, the kidneys are frequently stimulated to increased activity; and the smell of food strongly excites the salivary glands. The limb which has been palsied by a stroke of apoplexy emaciates and decays; and by dividing the nerves which supply the stomach, digestion has been effectually arrested. The stomach derives its nerves chiefly from the eighth pair, or *par vagum*; and experiment has ascertained that if a portion of this nerve be removed, the process of digestion is completely stopped. Two rabbits of about the same size were fed in the same way; in both the eighth pair of nerves were brought into view; in one rabbit a part of each nerve was removed; in the other, after being raised on a probe, both nerves were replaced without further injury. After the operation, both rabbits were allowed to eat as much parsley as they chose. When the rabbit, in which part of the nerve was removed, died (which happened in about twenty hours after the operation), the other was killed. In the former the food was found wholly undigested, and could not be distinguished from parsley chopped small with a knife; but in the latter, digestion had gone on as usual, and the food was found just in the same state as in a healthy rabbit. These experiments (and they have been variously repeated) strongly favour the view that a regular supply of the influence derived from the nervous system is necessary to the process of secretion. But the curious fact is, that the absolute continuity of the nerves, through which this influence is to be transmitted, is not indispensable for its conveyance. Dr. W. Philip and Mr. Brodie state, that if the cut ends of a divided nerve be placed at a distance of not more than a quarter of an inch from each other, the current of nervous energy is not interrupted, and that the secretions of the organ to which the nerve is sent go on as usual; but that if a larger portion of the nerve be removed, so as to separate its divided extremities to a greater distance, the process of secretion is completely stopped.

It has been conjectured that this nervous influence is identical with, or at least is some modification of, the electric or galvanic fluid; and the arguments by which this conjecture is supported are ingenious, if not strong. Too little, however, is as yet known upon this point to sanction any inference; and there are some who feel strongly inclined to question altogether the interference of the

nervous system in the process of secretion. It is certain that the mole, or imperfect child, which has no nervous system, attains a very considerable size; that a palsied limb can inflame and suppurate; and that the nostril and ear of the palsied side secrete as actively as those of the sound side. These and many analogous facts are well known; and if secretion can in any case be performed without nerves, or after the nerves which do exist have lost their power by disease, the doctrine, which holds nervous energy to be indispensable to this function, is not, perhaps, sufficiently established; while, at the same time, it cannot be denied, that no other view is in the abstract more plausible, or, when applied to life, can illustrate a greater variety of phenomena.

Absorption.

It has been more than once observed that a constant round of expenditure and supply is absolutely necessary to the continuance of existence. Parts and organs, which are healthy and in great requisition at one period of life, become injurious or useless at another; new functions are silently establishing themselves upon the ruins of the old; and the changing circumstances, through which man passes during his journey from tender infancy to decrepit age, are faithfully met by corresponding and suitable alterations in his structure. To have those substances which are secreted taken up and removed, when they are no longer necessary, is, therefore, as essential as to have them at first secreted; and a new function, called *absorption*, has been established for this purpose. Nutrition is the compound result of secretion and absorption, and the derangement of either is equally injurious. In fever absorption is much more active than secretion; hence rapid emaciation is one of the most striking features of that disease: while, in dropsy, more matter is deposited by the arteries than the absorbents can remove. To preserve these two functions in a state of balance is the design of Nature; so that no more matter may be secreted than can be absorbed, nor absorbed than can be secreted. When thus equipped in activity, these two opposing systems co-operate to the same effect—nutrition; one particle succeeds another in slow and silent renovation; every part of the animal fabric is gradually withdrawn, and is as gradually rebuilt; and without the disturbance of a

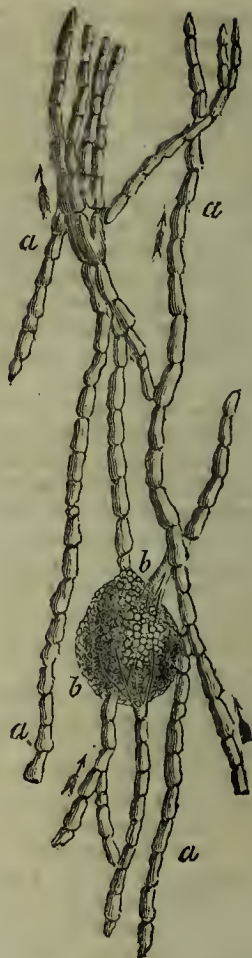
function, or the inconvenience of a tissue, this scientific masonry proceeds until the old building is carefully pulled down, and wholly reconstructed.

The apparatus, by which absorption is performed in the human body, consists of three parts,—lacteals, lymphatics, and absorbent glands. These three sets of organs compose a distinct system, denominated the *absorbent system*, which, from its exceeding minuteness, and the consequent difficulty of investigating its structure and laws, was almost entirely unknown until the beginning of the seventeenth century. The lacteals and lymphatics are, in structure, aspect, and function, essentially the same vessels. Both arise and terminate in the same manner, both are equally minute, both absorb their contents by the same principle, both circulate them by the agency of the same power, and both carry them to the same place of destination. But as the fluid which the lacteals contain resembles milk, being the chyle which is digested from the food, while that which the lymphatics circulate is not unlike water, and principally consists of refuse matter that is no longer adapted to the purposes of nutrition, these two sets of vessels are not only differently denominated, but in general receive separate and distinct descriptions.

Both lymphatics and lacteals are composed of two coats—an outer coat, which is not unlike the external covering of a vein, and an internal coat, which is dense, smooth, and polished. Between these two tunics some have supposed a third to intervene, analogous to the muscular coat of arteries; but the existence of such a coat has been rather inferred, because considered necessary, than proved by having been actually seen.

The internal coat is firm and strong, and is thrown into crescentic folds which, as in veins, perform the office of valves. These valves occur in pairs, are extremely numerous, and give to the absorbents that knotted and irregular appearance for which they are remarkable; every knot or enlargement indicating the presence of a pair of valves. Another obvious peculiarity of these vessels is their general uniformity of size. When an artery sends off a branch, it is sensibly diminished, or when a vein receives a branch, it is enlarged; but when a lymphatic or lacteal ramifies, little change of size, in general, occurs, whether the branch given off be large or small. (Fig. 84.)

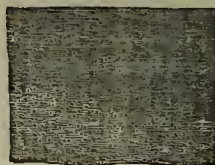
Fig. 84.



This figure represents the uniform size and the general appearance of the lymphatic vessels: *a a a a*, lymphatics in different stages of their progress towards the thoracic duct; *b b*, an absorbent gland, through which two of the lymphatics pass; the course of their contents is indicated by the direction of the arrows.

The *lymphatics* arise by very minute orifices from every surface of the body—from the peritoneum which lines the abdomen, from the pleura which surrounds the lungs, from the membranes which encompass the brain, from the mucous surface of the trachea, œsophagus, and stomach, from the external and internal surfaces of all the viscera, and from the external skin. (Fig. 85).

Fig. 85.



A portion of skin, the cuticle being removed, showing how the absorbents rise from it by open mouths.

They likewise arise from the interior of all cavities, from the surface of muscles, and, in fine, from every part of the body which is organized and supplied by blood-vessels. Like veins, the lymphatics are divided into two distinct sets. One set lie immediately beneath the skin, and may be easily rendered visible by injection with quicksilver; the other set are more deeply situated, and are devoted to the more internal parts of the body. These two orders of vessels inosculate freely with each other, and are similar in size, structure, and aspect.

The *lacteals* constitute a small but most important part of the absorbent system. They take their origin exclusively from the stomach and from the intestinal canal. The mucous or inter-

Fig. 86.



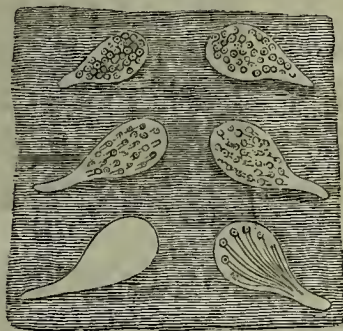
The appearance of the lacteals as they arise from the surface of the intestines, being white as milk.

nal coat of the intestines, in which the orifices of the lacteals are found, has a soft and fleecy surface, which is covered with small elevations called villi, not unlike the pile of velvet. Each of these villi seems to be composed of an artery, a vein, nerves and lacteals bound together by cellular tissue. Internally they are divided into cells, and they are exquisitely sensible, especially to the stimulus of chyle. They are extremely numerous in the duodenum, the jejunum and ileum; less so in the cœcum, and colon; and their number is still smaller in the stomach and the rectum. Liberkuhn states, that by means of the microscope it may be shewn that each villus terminates in what he calls an *ampullula*, which is an oval vesicle, having its apex perforated by lacteal orifices, through which the chyle, during its passage along the intestines, is taken up. (Figs. 87 and 88.)

Two distinct sets of lacteals can be discovered upon the intestines. The

first, or external set, lie immediately under the peritoneal coat, and run along the gut in a longitudinal direction; the second, or deep-seated set, lie beneath the muscular coat, and following the course of the arteries and veins ramify, like them, with great minuteness, two lacteals in general accompanying each (fig. 87) artery. At first, these two sets

Fig. 87.



This figure represents the villi as they appear when viewed through the microscope: the orifices of the lacteals are seen distinctly; the lowermost villus so turgid with chyle that no orifices are apparent.

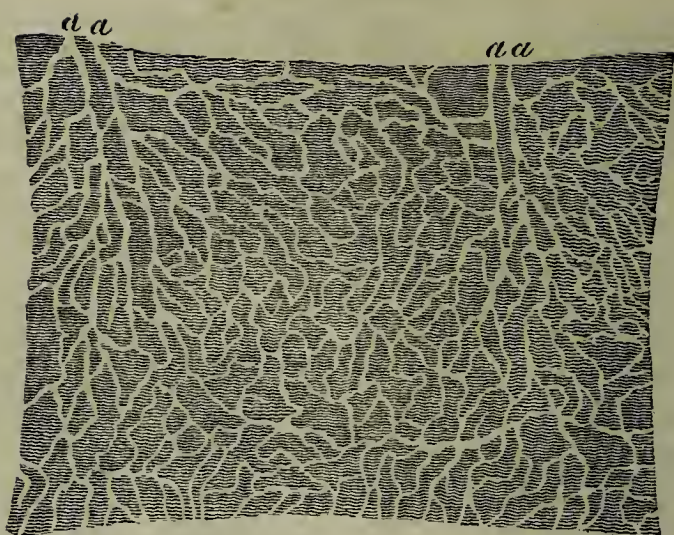


Fig. 88.

Two ampullulae magnified, turgid with chyle.

of vessels run at right angles with each other, but after the superficial lacteals have proceeded some length along the intestine, they turn up at an angle more or less acute, towards the mesentery, where they unite with the circular or deep-seated lacteals; after which they all ascend together, until meeting in their course with some absorbent gland, they enter its substance, and after passing through it, and uniting into one or two large trunks, they again issue from its opposite extremity, and prosecute their way towards the thoracic duct. In the adjoining figure, (fig. 90,) all these particulars are beautifully illustrated. A A, is a piece of the jejunum; b b b b, &c. are the superficial lacteals; c c c, is the mesentery by which the intestines are confined to the spine, and within the folds of which the deep-seated lacteals pass; d d d, the first order of the absorbent glands; e e e, the second order, through which the trunks that issue from the first order

Fig. 89.



a a, a a, four lacteal trunks, formed by an infinity of smaller lacteals, which arise from every part of the surface of the intestine.

pass; *ff*, the receptaculum chyli, or the thoracic duct; *ii*, lymphatics commencement of the thoracic duct; *g*, coming from different parts of the body,



Fig. 90.



and uniting to form the receptaculum chyli; *h*, the aorta.

The thoracic duct, *g*, or great trunk of the absorbent system, is formed by the union of the lacteal trunks with the two large lymphatic vessels which have been before described. The duct, at its commencement, is generally somewhat larger than at any other part, and this enlargement has received the name of *receptaculum chyli*, (or receptacle of the chyle *f f*); which varies very much in size, being in some instances scarcely perceptible, while in others it has been found no less than half an inch in diameter. This receptacle is situated upon the second or third vertebra of the loins, and the duct, as it issues from it, lies beneath the right arch of the diaphragm. After getting from under this muscle, it proceeds, in company with the aorta, along the right side of the spine, until it reach the fifth vertebra of the back; where it passes over to the left side of the spine behind the œsophagus. It then, ascending behind the left earotid artery, runs up to the interstice between the first and second vertebræ of the chest, where, after receiving the lymphatics which come from the left arm, and left side of the head and neck, it suddenly turns downwards, and finally terminates in the angle formed by the meeting of the subclavian and internal jugular veins of the left side.

As the general structure of glands has been already described, it will be necessary to add but little in relation to the anatomy of those which belong to the absorbent system. In form they are not unlike an olive, being oval or oblong. They are enclosed within an envelope of condensed cellular substance, and they are generally so situated, as to have their long axis placed in the same line with the vessels which pass through them. This investing membrane is so loosely attached to them, that tolerably free motion is allowed, and its cavity contains some viscid fluid. Some anatomists assert, that these bodies consist of convoluted vessels, while others maintain, with greater plausibility, that their internal structure is cellular. They are found in the greatest number in the neighbourhood of joints; they are very susceptible of disease, and since the absorbents pass through them in their progress to the thoracic duct, it is obvious that any important change in their structure must be productive of the most

serious consequences, by retarding or diminishing the supply of chyle.

Theory of Absorption.

THE outline, brief as it is, which has now been given of the anatomy of the absorbent system, will enable us to understand the course which the substances absorbed take in their journey to the heart. The lymphatics, arising by small and imperceptible mouths from every tissue of the body, and the lacteals, from the internal surface of the alimentary canal, take up the different substances they are destined to absorb, conveying them to one or other of the great absorbent trunks which have been described, and by those trunks pour their contents either into the left or the right subclavian vein. In this manner, provision is made for furnishing the function of secretion with a constant and adequate supply of material: whence it happens that, although secretions the most expensive to the system are daily and hourly elaborated, and the heart is every moment drained of its blood, yet the supply of chyle by the lacteals, and of lymph by the lymphatics, is so liberal and so regular, that the former can never fail through deficiency of fluid, nor the latter cease to act in consequence of being permanently emptied.

It becomes, then, a question of curious interest, by what power do the lacteals and lymphatics take up, in different parts of the body, those substances which they are designed to remove, and convey to the heart the substances they receive. There is here no forcing organ like the heart; there are no strong and muscular vessels like the arteries. Arising by small and almost invisible twigs from bone and muscle, from membrane and fat, and after a long and circuitous course through many opposing obstacles, at length terminating in a vein at some distance from the heart, it is obvious that the latter organ can exert but little influence upon the action of the absorbent vessels, and that neither the suction power of its right cavities, nor the propelling power of its left, can materially assist the ascent of the contents of the absorbents into the subclavian vein. It has been stated, that the supposed muscularity of the absorbents has never yet been demonstrated; and the doctrine, that their extremities are continuous with those

of the blood-vessels, in consequence of which the lymph is conceived to be propelled along the lymphatics, in virtue of the *vis a tergo* of the heart and arteries, is inadequate to explain the function, both because such continuity does not exist, and because, if it did, it could not account for the motion of the chyle in the lacteals, vessels which arise by open mouths from the surface of the intestines.

That capillary attraction has some share in the performance of absorption, is, we think, unquestionable; for after life is extinct, and after every living agent has ceased to act, the lacteals have been often seen not only full of chyle, but carrying their chyle actively forward towards the thoracic duct. This phenomenon can be accounted for only on the supposition, that the lacteals are, to a certain extent, capillary vessels, and that they can convey the chyle which they contain a certain length in virtue of their capillary power; hence, probably, the care that has been taken to confine the diameter of the absorbent vessels within a certain magnitude, and to furnish them abundantly with valves. Still, however, it is uncertain how far their capillary power extends, and to what degree it operates—the size of the thoracic duct, without doubt, incapacitating it for exerting such a power, and there is reason to believe that this, the more difficult part of absorption, is accomplished by some less mechanical and more efficient agency.

It has been already stated that both lacteals and lymphatics, before arriving at the thoracic duct, invariably pass through one or more conglomerate glands; that the internal structure of these glands is cellular, and that the villi of the mucous membrane of the intestines terminate in vesicles called *ampullulæ*, which, like the absorbent glands, are composed of cells. These are anatomical facts: it has long been a subject of inquiry why the absorbent vessels should so universally and invariably pass through one or more of these glands, although, in order to do so, it is often necessary that they should deviate from their direct course. It is well known, that the capillary roots of trees, and other plants, are terminated by small oval bodies called *spongiolæ*; that if these *spongiolæ* be removed, the roots to which they are attached lose their absorbing power, and that the vegetable dies. It is likewise known

that these *spongiolæ* are composed of cells, which are covered with a membranous envelope that contains some fluid, and it has been lately discovered by Dutrochet, a French physiologist of distinction, that these *spongiolæ* absorb nutritive fluid from the soil which surrounds them, in virtue of a principle which he has denominated *endosmose*. That this principle may operate with energy three conditions are necessary: First, that the absorbing medium be an organized vegetable or animal membrane; secondly, that there be a fluid enclosed within this membrane; and thirdly, that this internal fluid be denser than the fluid without, which is to be absorbed. By many very able and ingenious experiments Dutrochet has ascertained, that if these three conditions be observed, a power is generated which can raise fluid up a tube of any height, with a velocity proportional to the excess of the density of the interior over the exterior fluid. Into an instrument, which he calls an *endosmometer*, Dutrochet put a solution of sugar, of the density of 1.110, and immersed the end of the instrument in water. In two days, twenty-two inches of a column of mercury, the base of which was equal in diameter to the piece of bladder which was the absorbing membrane employed, was raised to a height of 45 inches and 9 lines; and the general conclusion to which the author arrives, after a great many arguments, facts, and experiments, which we can here merely refer to, is that by means of a common endosmometer, such as he employed, a syrup made of sugar, of the density 1.3, would generate an endosmotic force sufficient to raise a weight equal to four atmospheres and a half. Now, it is by no means improbable, that the absorbent glands are living endosmometers. Like *spongiolæ*, they are composed of cells; these cells are surrounded by a membrane, and this membrane contains a viscid fluid. The three conditions necessary to generate endosmose are, therefore, present and complete. The *ampullulæ*, which are attached to the extremities of the villi, and on which the lacteals open, are similarly constructed, and, probably, act by the agency of the same principle; and although the orifices of the lymphatics are as yet unknown, analogy perhaps warrants the conclusion, that they do not, in this respect, essentially differ from the lacteals, which, in all other points, they closely resemble.

From some experiments which have been made with the voltaic pile, it would seem that this endosmotic function, however, is intimately connected with galvanic electricity; but want of space precludes us from further detail.

Substances absorbed.

As has been already stated, the principal fluid which the lacteals absorb is chyle, while the variety of substances upon which the lymphatics act is great. Fluids of every consistence, solids of every texture, substances without as well as within the body, the hard bone and the soft brain, are alike decomposed and gradually removed. The rapidity with which their function is in some cases performed is remarkable. Thus, a few minutes after swallowing turpentine, the urine smells strongly of the odour of violets. In some forms of disease emaciation proceeds with astonishing rapidity; cases of dropsy not unfrequently occur, in which most extensive accumulations of water are removed in a few hours; it must be familiar to every one how soon, after drinking plentifully of some diluting beverage, the kidneys are excited to increased activity.

In all these instances the substances absorbed have either been in a fluid state, or soft, and easily broken down; and the action necessary to accomplish their removal does not seem so extraordinary as that which affects the absorption of bone, enamel, and other such hard animal formations. Still, however, bone and enamel are as easily, and as regularly absorbed as the most limpid fluids. In young animals the long bones are nearly solid, but those of old animals have a considerable internal cavity; the osseous matter in the interior of the young bone having been gradually removed at a more advanced period of life. When a portion of bone dies, or becomes carious as it is termed, ossific particles are deposited round the diseased bone, until an entirely new bone is formed, and the old bone, which is then included within the new, is completely removed by absorption. How structure so hard and imperishable can be so easily decomposed, and so finely comminuted as to be capable of entering such delicate vessels as the lymphatics, it is difficult to conceive, but it is probable that some chemical agent is at first employed, and that the absor-

bents begin to operate upon the substances they remove, only after the subtle chemistry of the animal economy has prepared them for their action.

Excretion

It appears, then, that the substances within the agency of the absorbent system consist of two classes. To the first belong all those substances which are denominated *recrementitious*, because they are more or less nutritive, and are fitted to maintain life; to the second, or the *excrementitious*, belong those which are exhausted, or injurious. Both are poured indiscriminately into the general circulation; the former are retained for the purposes of nutrition, and the latter are sent to the different excretory organs, to be there separated from the blood, and finally to be conveyed out of the system. Some of these effete substances are carried to the kidneys, and others to the intestines; while some are excreted in the form of bile, and others in that of perspirable matter. In this manner every animal particle is disposed of with rigid economy; nothing which can serve any useful purpose to the system is wasted; nothing which might prove noxious is retained, and every function, whether vital or animal, whether secretory or excretory, is thus made conducive to the support, the safety, or the pleasure of existence.

Conclusion.

WE have now completed our account of an extended circle of actions of great importance in the animal economy. After having considered the phenomena peculiar to life, the character by which the animal is distinguished from the vegetable, the common tissues which enter into the composition of the human body, and the properties possessed by each; we have traced the series of changes by which a morsel of food, when received by the mouth, is converted into blood, and the subsequent processes by which it is rendered a constituent part of the body, and as soon as it has performed its office, is removed out of the system, in order to make room for new matter. To accomplish these objects, the requisite circle of functions comprehends, as we have seen, 1st, DIGESTION, by which the food is converted into chyle; 2dly, RESPIRATION, by which the chyle is converted into arterial blood; 3dly, CIRCULATION,

LATION, by which the arterial blood is conveyed from the left side of the heart to the system, and returned from the system to the right side of the heart; 4thly, SECRETION, by which new particles eliminated from the blood are deposited, when formed, by the capillary vessels, and by which the body is maintained in a state of perpetual renovation; 5thly, ABSORPTION, by which the old particles are taken up as the new are laid down; and lastly, EXCRETION, by which old particles, that have served their office in the economy, are conveyed out of the system.

Of the apparatus by which these varied processes are performed, as well as of the processes themselves, we have given a brief account, which we have endeavoured to render intelligible to the reader; though we have been sometimes embarrassed by the difficulty of making known by description objects which cannot be well understood without being seen. Varied as the processes are, and numerous as we have seen the organs to be by which they are performed, yet it is obvious that they complete but one function—that of nutrition; and that they accomplish but one object—the preservation of the individual. The account of this circle of actions, therefore, by no means comprehends the entire science of physiology, which includes further the functions of locomotion, the functions termed the nervous, the sensorial, and the intellectual, and, finally, the function of reproduction. It is obvious that the former constitute the higher department of the science of physiology, to the consideration of which, it is possible, we may return at some future period.

However brief and incomplete the sketch here given of this science may be, yet it may at least suffice to convey a distinct conception of the nature of the phenomena of which it is its province to treat. In no other department of knowledge are the facts unfolded so curious, and in few are they of greater practical value. To shut out the fund of infor-

mation it contains from all who do not devote themselves to the medical profession, is as unreasonable as it would be to exclude the knowledge of chemistry from every one but the practical pharmacist. This treatise will not have been written in vain, if it should do no more than shew that the science of life is perfectly open to the student of nature, to the cultivation of which he may approach without the apprehension of meeting with any extraordinary difficulties. The obvious and peculiar advantages of this kind of knowledge are, that it would enable its possessor to take a more rational care of his health; to perceive why certain circumstances are beneficial or injurious; to understand in some degree the nature of disease, and the operation as well of the agents which produce it, as of those which counteract it; to observe the first beginnings of deranged function in his own person; to give to his physician a more intelligible account of his train of morbid sensations as they arise; and above all, to co-operate with him in removing the morbid state on which they depend, instead of defeating, as is now, through gross ignorance, constantly done, the best concerted plans for the renovation of health. It would likewise lay the foundation for the attainment of a more just, accurate, and practical knowledge of our intellectual and moral nature. There is a physiology of the mind as well as of the body; both are so intimately united, that neither can be well understood without the study of the other; and the physiology of man comprehends both. Were even what is already known of this science, and what might be easily communicated, made a part of general education, how many evils would be avoided, how much light would be let in upon the understanding, and how many aids would be afforded to the acquisition of a sound body and a vigorous mind;—pre-requisites more important than are commonly supposed, to the attainment of wisdom and the practice of virtue.

(5)
LINDLEY, John

VEGETABLE PHYSIOLOGY;

(OR, PHYTOLOGY*.)

TREATISE FIRST.

ANATOMY OF THE CONSERVATIVE ORGANS OF PLANTS.

INTRODUCTION.

PLANTS, whether regarded as individuals, or as grouped in the garden, the field, and the landscape, are objects of universal interest. The beauty of their forms; the delicacy, harmony, and splendour of their colours; the fragrance which they exhale; the refreshing verdure, and the convenient shade which we owe to them, besides their more important uses in contributing largely to our raiment, our sustenance, and our lodging; these connect our interests, and even our existence, with theirs: whilst the examination of their conformation, and the observation of their functions, as organized living beings, expand and elevate the mind, and raise its contemplations in wonder and in gratitude to the great Source of all life. This important subject is divided into two parts; the first comprehending the structure of those organs on which the growth and preservation of the plant depend; the second, the structure of those organs by which the continuation of the species is insured. The former part, treating of the *Conservative Organs*, makes the proper subject of this Treatise. But it is necessary, first of all, to explain the substances of which the organs, whether conservative or reproductive, consist.

CHAPTER I.—Of the Elementary Components of the Organs of Plants—Fluids—Membrane—Fibre.

ALL plants, however different in form and other qualities, are composed of

solid and fluid parts. The solid parts are generally permanent; that is to say, the organs which they constitute, when once perfected, are not subject to that waste and repair which the animal solid is supposed to undergo during life; but the fluid parts are changeable, varying continually both in mechanical admixture and in chemical composition.

The primitive solid components of the vegetable textures are *membrane* and *fibre*; from which are formed the common organic structures, the cellular and the vascular tissues*, and the varied combinations of these in the bark, *parenchyma* (or spongy, porous parts,) wood, pith, and medullary (or marrow) rays. The fluid elements are watery solutions of the soluble materials of the soil; from the decomposition of which, and the recombination of their ultimate components, by means of mechanical and chemical agency influenced by the principle of life, all the solid components, textures, and secretions are formed.

Vegetable Membrane is an exquisitely thin, transparent, colourless film, which resists the action of water and watery solutions in the living plant: but, when life ceases, is quickly acted upon by water, and reduced to mucilage. Du Hamel, a French philosopher of just celebrity, has asserted that vegetable membrane is composed of small organic fibres, arranged parallel to one another, and united by a glutinous substance: but no such structure can be detected by the microscope; on the contrary, it resembles a simple pellicle, or the film of a soap bubble, varying in transparency in different parts of the plant. In

* *Physiology*, from the Greek, a discourse of nature.

Phytology, also from the Greek, a discourse of plants.

* *Tissue*, a web, is the name for the soft and flexible parts of animals and plants—the *cellular tissue* is divided into cells, the *vascular* into vessels.

its simplest state it forms the sides of the cells of the cellular tissues; a little more condensed, those of the sap vessels; and still more condensed, the general covering, epidermis, or outer skin. It has also been supposed to derive its origin from minute globular bodies, found in the elaborated sap, which are dilated into vesicles to constitute the cellular tissue. There are other globules of a smaller size and more regular form, found in the interstices which frequently exist between the cells; and which, besides being the rudiments of future cells, according to M. Keiser, a distinguished German naturalist, are the cause of the different colours of the elaborated sap. It would be absurd to attempt a serious refutation of these hypotheses: we have only to recollect that plants are living bodies; that these globules are most probably merely nourishing matter, being found in great abundance in seeds, and wherever much nutriment is wanted; and that it is as easy to explain the most complex operations of structure, as to assign a satisfactory cause for the simple dilation of these particles into organic vesicles.

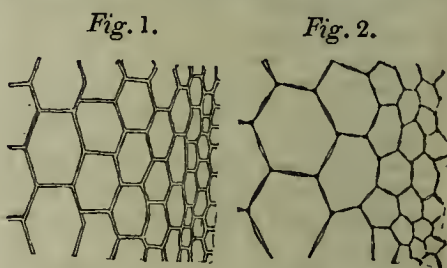
Vegetable Fibre is not so easily demonstrated as membrane, and is evident in one of the vegetable organs only, the spiral vessel, which is composed of one or more threads, twisted in a spiral manner so as to form a cylindrical tube. It is probable that these filaments owe their origin to the union of minute fibres, which can be detected in the elaborated sap and in all the proper juices of plants: this opinion, however, is also hypothetical; and it is not impossible that all the vegetable textures are modifications of membrane.

To enable us to examine the intimate structure of plants with advantage, the aid of a powerful single microscope is requisite; and the objects to be examined should be placed in a drop of clear distilled water. If we wish to examine the component parts of the plant, the portion containing them should be plunged in nitric acid, and the phial placed in boiling water, which must be kept at the boiling point for twelve or fifteen minutes. By this treatment, the parts composing the vegetable tissue lose their cohesion and become transparent, which greatly facilitates the investigation of them: the boiling, however, must not be carried so far as to disorganize the tissue; but, whenever

the transparency is produced, and the parts separate of themselves, the boiling should be stopped, and the parts disjoined by pincers, under distilled or filtered rain water*.

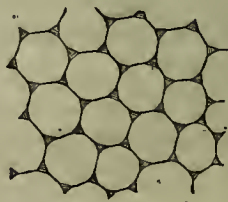
CHAPTER II.—Of the Elementary Parts composing the Organs of Plants—Cellular Tissue—Vessels.

1. *Cellular Tissue*.—If a thin transverse slice of the stem of any plant, or a slice cut across its stem, be put into a drop of pure water and placed under the microscope, it will be seen to consist chiefly of cells, more or less regular, resembling those of a honeycomb; as represented in *fig. 1* and 2, in which the cells are magnified 260 times. This



is the most common appearance of the cellular tissue when it is neither lax, nor compressed; but the form of the cells varies in different parts of the same plant, and also in different plants. The simplest form of the cell is the globular; the next is that of a twelve-sided figure, produced by a moderate pressure of six surrounding cells upon one, as displayed in the magnified transverse section of the stem of *Nasturtium* (*Tropeolum majus*) (see *fig. 3*); but,

Fig. 3.

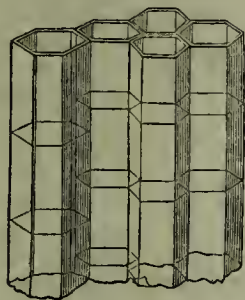


when the pressure of the surrounding cells is considerable, from each cell being stretched to the utmost, and the

* See *Recherches Anatomiques et Physiologiques, sur la Structure intime des Animaux et des Végétaux, &c.*, par M. H. Dutrochet, p. 9.

whole confined within a certain limit, the form of the cell is necessarily hexagonal. In a *vertical* or upright section, the cells are generally longer than they are broad, and appear to be double six-sided pyramids with their points cut over. (See *fig. 1.*) In some plants, however, they seem to be six-sided figures transversely divided, or ranges of small cylinders, as in the Sugar-cane (*Saccharum officinarum*) (*fig. 4.*); whilst in

Fig. 4.



others, as, for example, the Banana (*Musa Paradisiaca*), they are flattened, and so arranged as to leave large triangular interstices between them.

In the greater number of plants, the form of the cells in the bark and in the pith is nearly the same. In annual and herbaceous plants, the cells are almost all uniform in figure, when viewed in a transverse section of the stem; but in a vertical section those of the exterior part of the bark, and those surrounding the vessels, are longer and of a more tubular character than the others; and resemble in some respects short pointed close tubes united obliquely at their points. Oblong cells are always found surrounding the vessels, both in succulent annuals, and in trees and shrubs; and it is probable that this arrangement is connected with the change which the sap undergoes in becoming the proper juice of the plant. These elongated cells, disposed in bundles, and crossed with the horizontal cells of what are termed the medullary rays, form the whole of the inner bark (or *liber*); and, with the addition of sap vessels, they form also the wood. In the medullary rays, which are those diverging lines seen by the naked eye running from the centre to the circumference, in a transverse section of a *ligneous* or wooden stem, and commonly termed *insertions*, the cells resemble those of the pith; but they

are much smaller, and nearly disappear, from compression, in the old wood.

The size of the cells varies in different plants, and in different parts of the same plant. In general they are smallest in the leaves, larger in the roots, and largest in the stems of the same plant; and larger in annual and succulent plants than in trees and shrubs. In ligneous plants, the cells of the pith are larger than those of the parenchyma, or porous, spongy substance, and are visible to the naked eye; but in some parts of the plant they are so minute as to require a million to cover a square inch of surface*.

If each cell be a distinct vesicle, the partitions between the cells must be double; and this is rendered evident, under a powerful microscope, by the interstices which are apparent at the angles of the cells, when these are not fully distended, as in *Nasturtium*, (see *fig. 3.*) These interstices, or intercellular canals, as they are termed by some vegetable anatomists, vary greatly in size. In some plants, as *Calla Ethiopica*, they surpass the cells in magnitude; whilst in others, as *Sassafras*, they are scarcely visible. In both states, M. Keiser asserts that they contain proper juices; and, also, that they are the channels through which the sap rises; but, it is not probable that a function so important to the vegetable economy would be allotted to such casual organs. The conjunction of the cells with the vascular system differs according to the nature of the contiguous vessels, as will be afterwards explained.

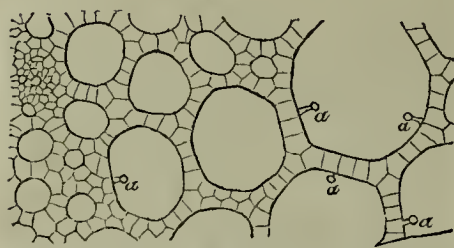
The cells are empty, or rather filled with air, in some parts of plants; but, in other parts, they receive and transmit fluids. In aquatic plants, in which there are large reservoirs of air, the cells of the parenchyma inclose bundles of vessels, whilst those which answer to the pith in other plants contain air only; and in trees and shrubs, although the cells of the pith contain an aqueous fluid, in the young or succulent state of the twig, yet they contain only air at a later period, when the twig becomes woody.

The air-cells, or rather reservoirs of air, of aquatic plants, are separated by partitions of cellular tissue, as is well illustrated in the greatly magnified sec-

* Hooke's *Micrographia*, p. 114.

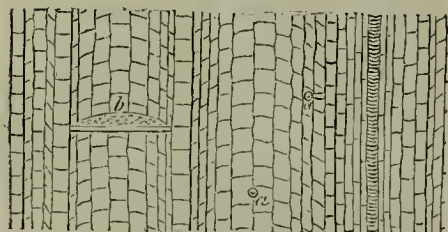
tion of the stem of *Calla Ethiopica*, (fig. 5.) They resemble short cylinders

Fig. 5.



or tubes divided by cellular diaphragms at irregular distances; see fig. 6, in

Fig. 6.



which *b* represents a diaphragm in a vertical section of the same stem. They are most frequently found in the centre of stems and in leaves, rarely in roots, and never in the woody part of plants. Their interior surface is sometimes smooth, as in the Banana; sometimes rough, as in grasses; in a few instances, they are filled with small cells, formed of an extremely thin membrane, and containing air; and, in others, as *Calla*, globular and radiated bodies, supported on foot-stalks (*a*, figs. 5 and 6.) are seen rising from their sides, and pointing towards their centres. Small air-cells, similar to those found in the air reservoirs, are also sometimes observed in the large vessels.

Such is the cellular tissue: it enters as a component into almost every part of the vegetable structure; and some of the less perfect plants seem to be altogether composed of it. It is highly probable that the most regular form of its cells, the hexagonal, arises from the pressure of the original globular vesicles upon one another: a fact which may be easily illustrated by agitating a solution of gum in a phial only one-third full: the air is involved in the mucilage and produces a froth; the cells of which are hexagonal, owing to the limits opposed to their expansion by the sides of

the phial. We also observe in the spawn of the frog, the ova or eggs of which are deposited in reservoirs close to the termination of the oviducts, that the gelatinous cells, which surround and form a covering to each egg, assume the hexagonal figure, from dilating in a limited space. The cellular tissue, besides containing water, fluid, and air, is the repository of mealy, sugary, resinous, oily, acid, and saline secretions: it is the medium also by which the descending proper juice, or elaborated sap, is diffused sideways through the plant; and many changes, effected by electrochemical agency, occur in the juices which fill its cells. Such, indeed, is the simplicity of the vegetable structure, that there is every reason for believing that the functions of secretion and nutrition are performed solely by the cellular tissue. The influence of vitality is thus beautifully displayed: the cells of the living plant, swollen with fluids, retain, during life, their figure; change the fluids they contain into others of the most opposite quality; and constitute a sufficient barrier to prevent them from mingling together: but, as soon as life is extinct, the sides of the cells yield, the secretions mingle, and, if circumstances be favourable, decomposition proceeds, permitting the chemical affinities, which had been controlled during the life of the plant, again to exert their influence.

2. *Vascular Organs*.—If the branch of a vine, or of any other tree, be cut transversely early in the spring, the sap will be observed to sweat out from numerous points over the whole of the cut surface, except that part which the pith and the bark occupy; and if a twig, on which the leaves are already unfolded, be cut from the tree, and placed with its cut end in a watery solution of Brazil wood, the colouring matter will ascend into the leaves, and to the top of the twig. In both these instances, a close examination, with a powerful microscope, will demonstrate that the sap perspires from the divided tubular portion of the stem, and that the colouring matter rises to the top of the twig, through real organic tubes: these are the sap, or conducting, vessels of the plant. But if we examine a transverse section of the vine, or of any other tree, at a later period of the season, we find that the wood is apparently dry, whilst the bark, particularly that part next the wood, is swelled with

fluid. This is contained in vessels of a different description from those in which the sap rises : they are found in the bark only, in trees, and have been named *proper vessels* ; but they may with more accuracy be termed *returning vessels*, from their function of carrying downwards the sap, after its elaboration in the leaf.

From the nature of the pith in trees and shrubs, no vessels are requisite in that part, and none are found in it ; but they are found in every part in herbaceous plants. Thence we ascertain that the oldest and most compact plant, (as Hedwig, a distinguished naturalist, of Leipsic, who died in 1799, remarked,) is but a collection of vessels and cells, which have nothing of the character of a solid, except the thin membranous coats by which they are formed.

The general figure of the vegetable vessels is cylindrical ; but the vessels are so minute that the greatest of them is scarcely visible to the naked eye. Hedwig measured the largest vessel in the stem of a gourd ; it appeared $\frac{1}{15}$ th of an inch in diameter, under his microscope, which magnified 290 times, so that its real diameter was the 3480th part of an inch ; and Leuwenhoeck, a citizen of Delft, who died in 1723, and was an accurate microscopic observer, reckoned 20,000 vessels in a morsel of oak about $\frac{1}{15}$ th part of an inch square. Notwithstanding their minuteness, however, the characters of the vegetable vessels can be tolerably well ascertained by the aid of the microscope.

The vessels of plants are generally collected in bundles or *fasciculi*, each containing from three to a hundred or more vessels. They occasionally, however, apparently ramify, but not like the vessels of animals, out of greater into less ; for the ramification, if it can be so termed, is of the same diametrical size as the trunk of the vessel. It is also commonly supposed that they do not open into one another by what anatomists term *anastomosing**, even when the end of one seems to open upon the side of another ; but, nevertheless, a true union of this kind has been observed in the vessels of leaves.

In describing the structure of the vegetable vessels, we may arrange them, first, according to their functions, or as Conducting vessels, and Returning ves-

sels ; and, secondly, according to their similarity in point of structure.

A. *Conducting Vessels*.—The first of these vessels which was discovered is the simple spiral. It was described nearly about the same time by Malpighi, a professor at Bologna, who died in 1694, and by Dr. Grew, an English physician, and secretary to the Royal Society, who died in 1711 ; and it has lately been supposed by Keiser to be the original of all the other varieties of vegetable vessels, which he asserts are merely changes of the spiral. This opinion receives considerable support from the fact, that spiral vessels are found in all young plants ; and that they are the only kind observed in some of the inferior tribes of vegetables. But there is another kind of vessel, the *annular* or ring-shaped, which exists as early as the spiral vessel, in many young plants, and, therefore, cannot be a transformation of the spiral : indeed, Keiser's theory of the manner in which he supposes this change to be effected is the least satisfactory part of his excellent work†. We are, therefore, satisfied that there are two primary forms of vegetable vessels, the *spiral* and the *annular*, of which all the others are modifications or varieties.

A. a. 1. *The Simple Spiral*. If a leaf-stalk of Dogwood (*Cornus sanguinea*), or of the Elder (*Sambucus nigra*), or if the fleshy scale of any bulb, as, for example, that of the White Lily (*Lilium candidum*), be cautiously broken, and the parts drawn asunder, the spiral vessels will be seen, like screws, partially unrolled. They are formed of one or more opaque, silvery, shining fibres, turned in a spiral manner, generally from right to left, so as to form a hollow cylinder, as represented in *fig. 7*. The spires are

Fig. 7. Fig. 8.



* From a Greek word, signifying to open the mouth.

† *Mémoire sur l' Organisation des Plantes*, &c. &c. Haarlem, 1814.

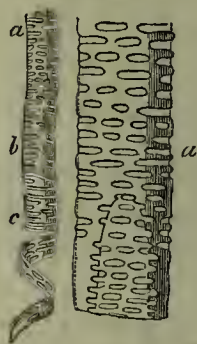
generally in contact, and the vessels are cylindrical, except when many of them are compressed together, in which case they are irregular. It has been supposed that the fibre forming the spiral vessel is hollow; but, when we consider that the diameter of the vessel itself, as Hedwig has ascertained, is less than the 3480th part of an inch, this is not very probable. In some plants, also, as the Reed (*Arundo donax*), the fibre is evidently flattened. The spiral is sometimes formed of one continuous fibre, sometimes of several parallel fibres adhering together; the numbers varying from one to nine, as in *fig. 8*. The fibres are tenacious and elastic; for, when forcibly stretched, they contract and again roll themselves up, on the stretching power being withdrawn. The spiral vessels are the smallest of the conducting vessels; and differ in size in different plants, and also in the same plant at different periods of its growth. The less perfect the plants are, the smaller these vessels are found to be. They are larger in annual and in succulent plants than in woody plants; in some of which, for example, Guaiac (*Guaiacum officinale*), and the Fir tribe (*Pinus*), they are very small. They are smaller in grasses than in succulent herbs; and in some plants, as *Chara*, Grass-wrack (*Zostera*), Duck-weed (*Lemna*), and Hornwort (*Ceratophyllum*), they have not hitherto been detected. In the young plant of the Balsam (*Impatiens balsamina*), they have not at first the diameter which they acquire as the plant advances in age. They differ also in size in different parts of the same plant, being generally largest in the stem, and in the footstalks of leaves.

The spiral vessels are found in the earliest stage of the growth of the plant, even in the plantule or embryo in the seed. They stretch through the whole length of the plant, from the roots to the leaves and flowers, following the various curvatures of the stem. They are generally disposed in fasciculi or bundles, the smaller vessels of the group being always those next to the pith. The cells in the vicinity of these bundles are smaller in the ratio of their proximity; but there is no evident direct communication between the cells and the spiral vessels. In succulent plants they are found involved in the cellular pulp or the parenchyma; in woody plants, they always surround the

pith, in the young shoot; and they form the greater part of the midrib of leaves and its ramifications, or what are erroneously termed veins and nerves, in leaves. They are also found in the *calyx* or flower-cup; the *stamens*, the *pointal*, and the other parts of the flower; and in the *cotyledons* or lobes of the seed.

A. a. 2. The *Reticulated Vessel* is a modification of the simple spiral, in which, the spires having become distant, the interstices are filled up in part with new fibres that pass diagonally from one turn of the spire to another, as if a branch from the original fibre; as in *a b c*, *fig. 9*. The whole of the spaces,

Fig. 9.



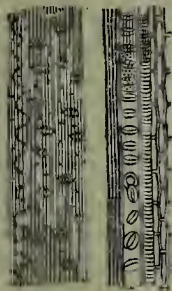
however, between the spires are not filled up by branched fibres; and therefore clefts or openings are left, which, from the *reticulated* or net-like aspect they produce, have given rise to the name of the vessel. Reticulated vessels are not found in young plants, being the result of a change produced by the advanced growth of the plant. They are found in a few plants only; but in some, as the Balsam (*Impatiens balsamina*), at its full growth, they are the only kind of vessel contained in the root, in which part they occur more frequently than in the stem. In the fasciculi they are situated towards the bark.

A. b. 1. The *Annular Vessel* is a primary form of vegetable vessel, named from its being formed of fibres like rings, instead of one continuous spiral fibre. According to Keiser, this vessel is an accidental production, caused by the tearing of the spires, which fall into simple rings, between each of which a membrane is formed. But independent of the fact already noticed, that the annular vessels are found as early in some plants as the spiral vessels, we

ourselves have traced them from their earliest appearance, and are satisfied that the rings never formed parts of a spiral vessel.

The annular vessel consists of a simple transparent membranous tube distended by rings, which are retained in their places by minute needles, which can be separated from their vessels in Spider-wort (*Tradescantia*), and some other plants. Fig. 10 exhibits the ear-

Fig. 10. Fig. 11.



liest formation of the vessel, at a time when the rings exist separate in the cellular mass, without the membranous tubes; and fig. 11, the perfect vessel. The rings are generally separated from one another only by a space equal to their own diameter; but they are occasionally at a distance of six or eight diameters. The annular vessel is found in many plants; and is particularly distinct in Spider-wort and Balsam.

A. a. b. 1. The *Punctuated Vessel* derives its origin both from the simple spiral and the annular vessel. When the spiral is its original, the spires are separated, and the intervening space filled with a connecting membrane, which is thickly studded with round oval dots, as displayed in figs. 12 and 13. When the annular is the

Fig. 12.



Fig. 13.



original, the membrane covers the rings, which can sometimes be moved within the tube as in the Reed (*Arundo donax*). The dots, which surround the vessel in parallel rows, appear, in some plants, to be pierced in the centre, and it is probable that this is the case in all. The membrane in the spiral punctuated vessel is not present in the young plant, and does not form until the leaves of the plant are in their adult state. In both varieties of the vessel it is at first transparent, and becomes opaque by age. It is the largest, in respect of diameter, of the vegetable vessels; and, in the fasciculi of vessels in the stems of herbaceous plants, it is always the nearest to the bark. It is present in the root, the formed wood of stems, in branches, leaf-stalks, and the midrib of leaves. In old and hard wood, as of the oak and the chesnut, the punctuated vessel appears as if it were branched.—(See fig. 12.)

A. a. b. 2. The *Beaded Vessel* is a modification of the punctuated and the reticulated vessels. It resembles a chain of oblong ovate cells, or beads; (fig. 14.) whence it derives its name.

Fig. 14.

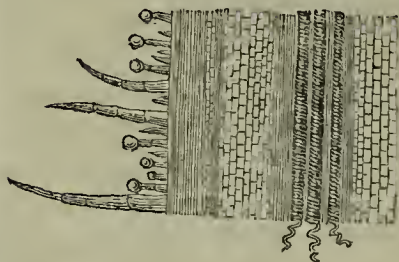


It is found only in the knots of the stem, and the tubercles of the roots; and seems to be intended for uniting the other vessels with one another.

Sometimes two or more modifications of structure are seen, at the same time, in the same tube. This arises from the natural tendency of the simple spiral vessel to change into the punctuated vessel; and both this and the reticulated into the beaded vessel. If the stem of a gourd be examined at different periods of its growth, or in different parts of the plant, between the root and the top of the stem, we shall find that, in the young plant, or at the newly unfolded extremity of the old plant, the

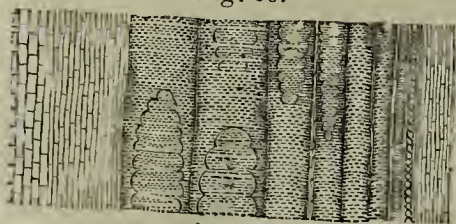
vessels are all simple spirals. As the plant advances in age, each of the vessels already formed becomes punctuated, and new spiral vessels appear on the opposite side of the fasciculus; and this transformation of spiral into punctuated vessels proceeds until all the vessels in the oldest part of the stem, that are next the root, are punctuated vessels. This is well illustrated in the two portions of the stem of the same gourd represented in *fig. 15*, and *fig. 16*. In

Fig. 15.



the first, taken near the top of the plant, the vessels are few, and all simple

Fig. 16.



spirals; in the second, taken near the root, the number and magnitude of the vessels are greatly increased, and they are all punctuated. This illustrates the remark that the vegetable solid is permanent; for, by the growth of the plant the original spiral thread is stretched, and the membrane is added to form the altered vessel. As a proof, also, that the spiral and the annular vessels are not varieties of one another, Keiser, whose accuracy of observation can be relied upon, asserts that the punctuated and the reticulated vessels are never found in the same plant.

We cannot here enter into a minute investigation of the functions of the vegetable vessels; but it may be proper to state, that the most contradictory opinions regarding them prevail. It is undoubted that, in early spring, and in autumn, fluid is found in all the vessels; and even those persons who maintain

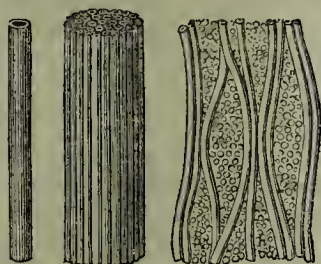
that the spiral vessels are *tracheæ* (*wind-pipes*), or air-vessels, have been forced to admit that they occasionally carry sap. The great difficulty rests, undoubtedly, with the spiral vessels; for those which have membranous sides can be intended for no other purpose than to carry fluids. Whilst the subject remains undetermined, the following hypothesis may be hazarded:—that the spiral vessels are intended for conveying upwards the sap, in young plants and shoots, and that they accomplish this with a very moderate impulse, owing to the easy contraction of the fibre, lessening the diameter of successive portions of the vessel, and thus raising the sap forced into it by an impulse communicated in the radial fibrils; but that, as in the more advanced age of the plant the strength of the coats of the radial fibril increases, no contracting power in the coats of the vessels becomes requisite, and all that is necessary is a sufficient strength of the coats of the vessels to resist the pressure of the ascending fluid, which receives its impulse in the roots, and ascends as if it were through dead tubes. The nature of this impulse, and the effect which it produces on the progress of the sap, (for there is no circulation of that fluid) will be fully explained in the treatise on the *functions* of plants.

B. Returning Vessels.—It has been already stated, that as soon as the leaves begin to appear, the sap ceases to flow from the wood if it be wounded; but that this does not proceed from the sap not continuing to rise, but, as Dr. Hales has expressed himself, ‘from the attraction of the perspiring leaves being greater than the power of *trusion* (a thrusting) from the column of water.’ The bark, however, at this time, is full of fluid, which is evidently descending, a fact which was first noticed by M. de la Blaise, and has since been confirmed by Mr. Knight*; and this fluid is carried downwards in vessels which are situated near the inner margin of the bark. They run, in straight parallel fasciculi (or bundles), close to the wood; but, as a new layer of these is added every year, and the former layers are pushed outwards, those at a distance from the wood separate from one another, and produce a mass of network,

* Mr. T. A. Knight, President of the Horticultural Society.

the meshes of which are filled with cellular matter. Each vessel is a simple entire tube, of a small size. The vessels in the bark of trees and shrubs, which have a copious, thick juice, are arranged around reservoirs of this juice, in the same manner as the oblong cells are arranged around the other vessels; but, in herbaceous plants, those in which the vessels are distributed, in distinct bundles, through the parenchyma, they form part of each fasciculus, in conjunction with spiral or annular vessels. In figures 17, 18, 19, is represented

Fig. 17. Fig. 18. Fig. 19.



each of these states of the returning vessels.

CHAPTER III. — *Of the Compound Organic Constituents, or Common Textures of Vegetables—Epidermis—Bark—Wood—Pith.*

By the terms *Compound Organic Constituents* and *Common Textures* are understood those parts of the plant into which the elementary organs enter as components; and which, nevertheless, are themselves only components of the vegetable members. They will be described in the order in which they are found in the trunk and the branches of trees, proceeding from the exterior or outward skin to the centre of the plant.

1. The *Epidermis*, or vegetable cuticle (*Epiderma cuticula*), is an extremely thin membrane or pellicle, which, variously modified, extends over the surface of every part of the plant, from the spongy fibril of the root to the delicate petal of the flower, and even to the fruit; interposing a barrier between the living organs and all extraneous substances. It is furnished, in leaves, and in some stems, with extremely minute vessels, which spread over it like network, the form of the meshes differing

in different plants, but all terminating in spiral vessels at the edge of the leaf. In herbaceous plants, and in young and succulent twigs, the epidermis is transparent, and, with a few exceptions, colourless, receiving its apparent colour from the parts which it covers. In old trees, however, it appears to be coloured not only in different plants, but in different parts of the same plant: thus in the Birch (*Betula alba*), it is white on the trunk and brown on the young branches; but this colour probably belongs to the *cutis*, or inner skin, which it covers. In young and annual plants, it is applied so closely over the cellular tissue as to be scarcely separable from it: but, in perennial plants, it is annually reproduced, and the old epidermis pushed outwards. The doublings of layers thus accumulated has led to the erroneous opinion that it consists of several layers. Before it separates, it becomes opaque and apparently coloured. The new epidermis also is perfected before the old exfoliates; and in this manner the parts which it is intended to cover are always protected.

The epidermis is generally supposed to be perforated by the organic pores which are found on some parts of the surface of the plant; but it is probable that it enters these pores as a lining membrane, instead of being perforated. These pores, which shall be particularly noticed when leaves are described, are not found in all plants; they are not present, for instance, in the Lichens, nor in many mosses, nor in all plants which grow under water; neither are they to be discovered in every part of the same plant; never on the trunk, except when the plant is devoid of leaves, and never on the root. They are found on both sides of the leaf in grasses and in many other plants which have erect leaves; on the inferior side, or disk, only of the leaves of trees and of shrubs; on the upper side only of floating leaves; upon the *calyx*, but seldom upon the *corolla* of flowers; and on the stamens and the style in a few plants. They are found also in the outward rind or skin coverings of fruits, and of seeds; and on the cotyledons or seed lobes. They differ in size in different plants; but in the same plant their dimensions are always the same. The hairs, prickles, and glands, which are present in stems and in leaves, are merely extensions of the cellular tissue, covered with epidermis.

The epidermis is probably intended for the protection of the cellular tissue from the direct action of the atmosphere; and, in some instances, to limit the growth of parts. When it is accidentally destroyed on the succulent twigs of perennial plants, it is quickly regenerated; but in annual plants, and on the leaf and the flower, it is never renewed. It gives free passage to moisture, and exhales or gives out vapour, and absorbs or sucks it in; and it performs the latter function independently of pores, which cannot be detected on the absorbing surfaces by the most powerful microscopes. Some vegetable physiologists, among whom is M. Mirbel, have regarded it as merely condensed cellular membrane, altered by exposure to air and light: but the majority more correctly admit that the epidermis is a distinct organized membrane.

2. The *Bark (cortex)*, comprehends four very distinct layers or parts—the epidermis, which has been already described, the *cutis*, (inner or thick skin,) the cellular integument, (or covering,) and the inner bark, or *liber*, each of the three last of which we shall separately describe.

a. The *Cutis* consists of two layers, the outer of which is the pellicle or epidermis, already described, and the inner a composition of transverse cells which stretch betwixt the epidermis and the cellular integument. But this structure varies in different plants; thus, in the Horse Chesnut (*Æsculus hyppocastanum*), these cells resemble transverse vessels opening upon the surface of the stem; in the Lesser Periwinkle (*Vinca minor*), there are three series of such cells; whilst in the Laburnum (*Cytissus laburnum*), there is only one irregular layer. In young succulent shoots, the cutis is generally colourless and semi-transparent, transmitting the green colour of the cellular integument which it covers; but, in some instances, it is coloured; for example, white in the Birch (*Betula alba*), and yellow in the Japonica (*Aucuba Japonica*); and, as we have already remarked, it varies in colour in different parts of the same plant.

b. The *Cellular Integument (stratum cellulosum)* is composed of oblong hexagonal cells, ranging vertically, and varying in regularity in different plants. These cells are commonly filled with juices, which become greener the nearer

they approach to the light; and it is the transmission of this colour through the cutis and epidermis, which gives the green colour to the succulent twig.

c. The *Liber*, or *inner bark*, is of a whitish hue, and the texture fibrous to the naked eye: but, when it is examined by a good magnifying glass, it seems to consist of fasciculi of longitudinal fibres running in a waving direction and touching one another at certain points, so as to form oblong meshes, which are filled with cellular tissue; see *fig. 19*. These longitudinal fibres, under a powerful microscope, are found to be fasciculi of returning or entire vessels, situated between the cellular integument of the bark and the wood, and divided into meshes by the medullary rays, which extend from the pith through the wood into the bark; and there push between these fasciculi, to reach the cellular integument. This tubular texture has been termed *cortical fibres*, from the supposition that it is of a ligneous nature, an opinion which received some support from the fact, that when the liber is soaked in water, the intercellular part dissolves, and the oblong cells remain unaltered: but no doubt is now entertained that these apparent fibres are hollow tubes, the vessels which convey the elaborated sap downwards, to increase the solid diameter of the tree. When the liber of the Lace-bark tree (*Daphne la-getto*), is soaked in water and afterwards beaten, it forms a beautiful vegetable gauze, which might be worn as an article of dress. Oak bark, when it has been long exposed to the weather, exhibits a reticulated aspect resembling the above-mentioned gauze. The whole of the bark is annually reproduced, and the old layer pushed outwards. When it cracks vertically, there are formed the rough furrowed coats of the Elm, the Oak, and many other trees; when transversely, the multiplied layers of the Birch and the Currant; and when the crack is irregular and in both directions, the flakes which are thrown off by the Plane. Du Hamel demonstrated this fact, of the annual regeneration of the bark, and the pushing outwards of the old layers, by passing a silver wire through the young bark, in the middle of its thickness, and finding it some years afterwards in the decayed bark.

Neither spiral nor annular vessels, nor any of their varieties, are found in

the bark: but its vessels are the redundant already described. The whole of the cells of the liber contain secreted fluids; and it is this portion of the bark, therefore, that yields the various products which render certain barks useful in medicine and the arts.

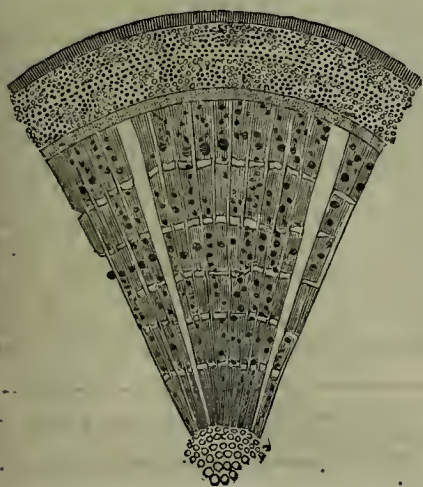
3. The *Wood (lignum)*.—If a young shoot of any tree or shrub be cut through transversely, there is perceived under the bark a cylinder of greater firmness than the bark, inclosing a spongy or cellular mass: this is the wood. If the tree, or the portion of it which is cut through, be several years old, several cylinders of wood are observed inclosing one another, or forming concentric layers around the cellular column or pith, and occupying the space between it and the bark. The outermost of these layers is always more succulent than those are which are within it, and is named *alburnum*. It is this part which, in deal, has a whiter colour, is more spongy and less durable than the more perfect, or *heart wood* as it is termed. These concentric layers are also perceived to be traversed by rays or lines diverging from the centre of the stem to its circumference, and are evidently of a structure different from the other part of the ligneous circles. On a closer inspection, aided by the microscope, this ligneous part of the tree is discovered to be formed of longitudinal fasciculi or bundles of vessels surrounded with oblong cells, which are traversed horizontally in various places by flattened masses of cellular substance, separating the bundles of vertical tubes and oblong cells, so as to display a re-

ticated appearance, when a perpendicular section of the stem or shoot of any tree or ligneous plant is examined. The wood, therefore, consists of two distinct parts, *concentric layers* and *medullary rays*, as represented in fig. 20.

a. The *Concentric Layers (strata lignea)*.—The vessels of which these consist are the punctuated, or the reticulated, or, under certain circumstances, the beaded, except in the first circle surrounding the pith, which contains simple spiral vessels. The oblong or elongated cells are arranged parallel to one another, except where they are separated by the medullary rays. The vessels in each concentric layer of wood are always larger in that part of it which is nearest to the centre of the stem, owing to their being formed in the spring when vegetation is most active; and smaller in the opposite portion of the layer which is formed in autumn: but in the fasciculi of herbaceous plants, in which there are no concentric layers, the smaller vessels are always towards the centre of the stem; although in Palms, which have also no concentric layers, the larger vessels are found in those fasciculi nearest the centre. The oblong cells contain fluids in the young or succulent state of the wood; but as this advances in years, they are filled with thickened secretions; and these becoming drier, and consequently harder, produce much of the solidity and firmness of wood.

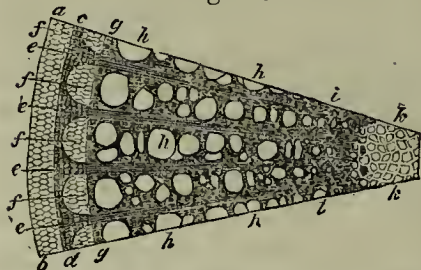
b. The *Medullary Rays (radii medullares)*.—The flattened masses of cellular tissue, which compose these, consist of oblong cells resembling the oblong cells which surround the vessels; except that they are horizontally arranged. These rays stretch from the first layer in the centre to the surface of the wood; and are there opposed by others situated in the *liber* or inner bark. In these rays the cells are more numerous in the middle of the mass, so that in a vertical section of a stem they appear to be of a lozenge shape. The cellular texture of the medullary rays has led them to be regarded as processes of the pith, and hence their name, the pith being as it were the marrow (*medulla*) of plants. But that this is an error seems evident, for the first layer of wood, the one next to the pith, has no medullary rays traversing it, although every subsequent layer is crossed by them. But this central layer differs from the other layers in several respects. It consists

Fig. 20.



of small oblong cells, imbedding a circle of simple spiral vessels, and a cellular lining or sheath which is interposed between the pith, and the spiral tubes. In herbaceous plants no medullary rays are perceptible until the plants have produced seed, and become woody, when they are evident; as displayed in fig. 21, the transverse section of the

Fig. 21.



stem of the French Bean (*Phaseolus vulgaris*,) in which *a b* represents the bark, and *c d* the termination of the medullary rays, *e e e e*, between which the spaces within the semicircles *f f f* are filled also with the cells of the bark: *g g* are the vascular bundles, consisting of large punctuated vessels *h h h h h*, and small spiral vessels *i i* close to the pith *k k*.

4. The *Pith* (medulla) is composed entirely of cellular tissue, which is at first filled with watery fluid; but gradually exchanges this for air, becoming dry before the first layer of wood is perfected, except near the final bud, or where branches are given off, in which places it retains its moisture. The cells of the pith in young stems and twigs are more regularly hexagonal than in other parts of the plant; but this alters, owing to different circumstances, as the tree becomes old. The pith is usually white, but in some instances it is coloured; as, for example, it is yellow in the Barbary (*Berberis*), pale brown in the Walnut (*Juglans regia*), fawn-coloured in the Sumach (*Rhus*), and pale orange in yellow-flowered Horse Chestnut (*Æsculus flava*). The diameter of the pith in many herbaceous plants, and in the majority of trees, continues the same in the full-grown plant as in the twig or the young plant: but in the Sunflower (*Helianthus annuus*,) and a few other plants, it increases in diameter after the spaces of the stem between the leaves cease to extend. The cavity which contains the pith is circular in the majority of plants; but it varies in

shape, being furrowed, oval, triangular, quadrangular, pentagonal, and hexagonal in many trees. It is also, in general, longitudinally entire; but in some trees, as in the Walnut, it consists of a succession of transverse diaphragms* intersecting the hollow cylinder of the wood, with the intervening spaces empty. See fig. 22.—In many herbaceous plants it is a mere lining sheath.

Fig. 22.



Such is the nature of the general components of the vegetable structure; let us next examine the members and organs into which these enter. They may be divided into two distinct classes: 1. The conservative members and organs, or those on which the life of the individual depends. 2. The reproductive members and organs, or those by which the species is perpetuated. The former comprehend the *root*, the *stem*, the *leaves*, and the *appendages* of these parts; the latter comprehend the *floral envelope*—the *productive organs*—and the *seed*.

CHAPTER IV.—Of the Structure of the Root—its Divisions—Mode of branching—Rootlets—Capillary Fibrils.

THE root, *Radix*, as commonly defined, is that part of the plant 'by which it attaches itself to the soil in which it grows, or to the substance on which it feeds, and is the principal organ of nutrition†.' There are, however, some exceptions to this definition; some roots are not fixed to any thing, but float loosely in water, as Duck-weed (*Lemna*), and some have no roots at all, but absorb their nutriment from the air by their general surface, as the genus *Tremella*. Roots, as they grow, generally assume a determinate form; and botanists have arranged them accordingly; but we must refer our readers to the subject of Botany, both for an account of the

* From the Greek word, signifying a fence or separation, or skreen.

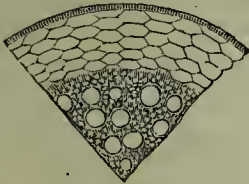
† Keith's System of Physiological Botany, vol. i. p. 33.

forms of roots, and of their relative direction in the earth.

The mature root consists of three distinct parts; the *body* or *caudex*, which is often divided into branches; the *rootlets*, which issue from the caudex and branches; and the fibrils, occupying the top and sides of the rootlets.

The roots of trees so closely resemble the stem in structure, that they have been named *subterranean trunks* and *descending stems*; and, on this account, we may refer to the description of the stem for information respecting the general anatomy of ligneous roots, at least as far as concerns the caudex and branches. In herbaceous plants this analogy is less close. When the root is *annual*, the caudex consists of a corticle and a thick cellular bark, which constitute a large proportion of the diameter of the root; and a central part, composed of oblong cells and vessels, disposed either in separate fasciculi, or in rings, or in rays as in the transverse section of the root of the Sweet-pea (*Lathyrus odoratus*), represented in *fig. 23*. The cortical cells are all hexagonal;

Fig. 23.



the sap vessels are the punctuated; those in the centre being generally the smallest; and they occupy the place of the pith, which is seldom found in annual roots, except near the top, where it changes into the stem. In those annual roots which secrete a white or a proper juice, all the cells are tubular, and arranged with great symmetry; and they appear to be conductors as well as reservoirs of the proper juice. The root of the White Poppy (*Papaver somniferum*), a few of the cells of which are

represented in *fig. 24*, affords a beautiful example of this structure. A contracting power might be suspected to exist in these cells, as the exudation of the juice from a transverse section of the root is much greater than could be contained in the range of divided cells; and on examination we find the cells of several successive ranges empty and shrunk; but in this case the exudation rapidly thickens, and favours the emptying of the entire cells, a fact satisfactorily accounted for by the theory of M. Dutrochet, which shall be explained in the Treatise on the Functions of Plants.

In *biennial roots*, the disposition of the parts is more varied than in annual roots. In the first season of its growth, the biennial root consists of a cuticle and thick cellular bark, surrounding a large central part composed of short hexagonal tubes, variously arranged; but often in rays proceeding from the centre to the circumference. These generally contain *mucus* or proper juice. The sap-vessels, even the smallest and most recently formed, are punctuated: they are larger in diameter than the tubular cells; and variously arranged in different plants, sometimes in rays through the central part, as in Burdock (*Arctium lappa*); sometimes in fasciculi, as in Hemlock (*Conium maculatum*); and, in other instances, in circles. The mucus in the tubular cells being appropriated for perfecting the flower stem, the flower, and the fruit, is absorbed as the fructification of the stem advances; and, as these are perfected, the cells are emptied and their sides become ligneous. It is this which renders the turnip, the carrot, and other eatable biennial roots unfit for the table, when the plants have flowered.

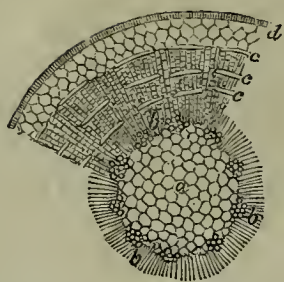
Perennial herbaceous roots are still more varied than either the annual or the biennial, in the proportion and relative position of parts: they may, however, be all described under two heads; those composed chiefly of *tubular cells symmetrically arranged*; and those composed of *common cellular tissue*.

If the root of Dandelion (*Leontodon taraxicum*), in the first year of its growth, be taken as an example of the first division, we find that it consists of a cellular pith, *a* (*fig. 25*.) surrounded by ten fasciculi of sap-vessels *b, b, b*, which are punctuated with oblong dots; a thick parenchymatous layer, consisting

Fig. 24



Fig. 25.



of oblong or short tubular cells arranged in rays, through which run numerous fasciculi of reductent vessels *c, c, c*, disposed so as to form concentric circles; and a bark *d*, formed of hexagonal cells, and covered with a thick cuticle. As the root advances in age, new vessels are added to the fasciculi of sap-vessels; and as they continue to increase, the original pith is so compressed, that the centre of the stem assumes the aspect of one vascular mass. New layers of cellular tubes and reductent vessels are also added on the exterior, the old vessels becoming opaque, whilst the cuticle with the cellular bark cracks, and both are annually pushed outwards; until, at length, the root appears, in a transverse section, even to the naked eye, to consist of a central vascular part, surrounded with concentric circles, alternately opaque and transparent. The vessels are variously dispersed in different plants; but, in all of this division of perennial herbaceous roots, the tubular cells are symmetrically arranged, and constitute the greater part of the root. If the root of Deadly Night-shade (*Atropa belladonna*) be taken as an example of the second division, we shall find that it is composed chiefly of oblong cells not symmetrically arranged, with one large fasciculus of punctuated sap-vessels in the centre, and several smaller fasciculi interposed, so as to form nine or ten indistinct, interrupted rays. In the second year, additional sap-vessels surround the central part; and, as the root advances in age, it resembles the ligneous stem in structure, having a pith, concentric circles of wood, diverging rays, and a bark.

Herbaceous roots are all originally spindle-shaped; but they sometimes become forked, in which case the sap-vessels of the caudex are divided according to the number of the forks, as if a skein of thread was divided into two

or three parcels. In truth, this division differs from branching, inasmuch as branches are new productions with vessels of their own, which may unite with, but are not a part of, those contained in the caudex. When any thing opposes the extension of the tap-root, or destroys a portion of it, then branches shoot out sideways; and this is probably owing to the addition in the extension of roots being always made at the point.

Rootlets (radicella), whether of ligneous or of herbaceous plants, project at right angles with the surface of the caudex, or the branch on which they are seated. Some rootlets are productions of the bark or the albumen of the stem; and are shot forth whenever the part is placed under the ground, or is surrounded with moist earth. Thus, if the branch of a tree or a shrub be bent downwards until it touch the ground, then pinned to the spot and slightly covered with earth, rootlets will be sent out from the under part of the branch; and if the branch be then separated from the tree, it will grow and become a tree similar to the parent: or, if a ring of bark be removed from a branch, and the part surrounded with moist earth, in the manner of grafting, rootlets will be emitted from the upper portion of the divided bark. Rootlets also come from the knots in the stems of grasses and similar plants, whenever they are brought into contact with moist earth: thence the advantage of rolling young wheat and grass; for whenever these rootlets are produced, additional stems also spring from the knots. The rootlets, which issue from the caudex of the root and the branches, proceed from the medullary sheath, and are united with the vascular fasciculi of the ligneous part of the root; but from whatever part they originate, rootlets consist of one large fasciculus of punctuated sap-vessels, generally arranged in rays, and inclosed in a cellular bark.

The *Fibrils (fibrillæ)* comprehend two parts,—the thread or capillary ramification of the rootlet, whence their name, and the *Sponglets (spongiolæ)*, which are seated upon their sides. The *fibrils* consist of a central fasciculus of vessels, inclosed by a cellular cortex and cuticle; the *sponglets* are oblong, oval, spongy bodies, very minute, and found only on the fibrils; (*a*, fig. 26, represents one greatly magnified.) When examined under the microscope, they

are found to consist of a porous cuticle, inclosing a circle of hexagonal cells, *b*, (fig. 26.) surrounding a fasciculus of vessels, *c*, which anastomose with, or open into those of the fibril. They shrivel up in a few seconds after the root is taken out of the ground, and lie so close to the fibril as to be scarcely visible (see *a, a, a*, fig. 27.); but, if the fibril be placed in water, they as rapidly expand again, swell, and project from its sides (*b, b, b*, fig. 27). The

Fig. 28.

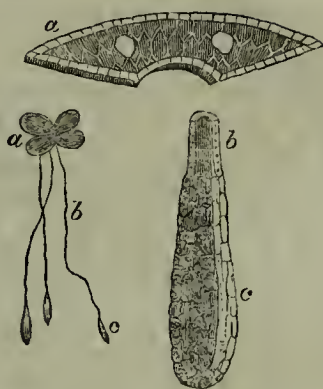
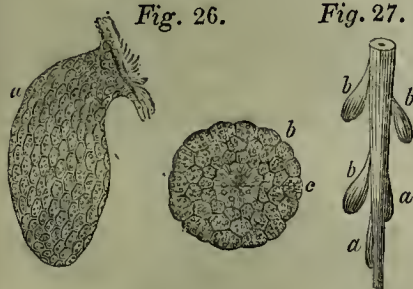


Fig. 26.

Fig. 27.



smallness of these bodies prevents their structure from being more fully developed. Some late experiments of M. Dutrochet, which have been already mentioned as important, have thrown great light upon the functions of these minute bodies: they render it probable, that these fibrils imbibe the fluid from the soil through the cuticle, aided by electrical influence: and the cells, swelling, push the fluid into the vessels, through which it rises, forced upwards by the impulse given to it from the continued imbibing of the swollen cells, and the resistance opposed to distension by their sides and those of the vessels through which it rises. Some families of plants, instead of this capillary fibril furnished with spongetlets on the rootlets, have a spongy knob at the upper point of the rootlet; and, in some floating plants, as Duckweed (*Lemna*), and *Callitriche*, there is a small coif or hood at the extremity of the root, as represented in fig. 28, in which *a*, in the small figure, is the floating plant, *b* the rootlet, and *c* the coif. The structure of these parts is displayed in the dissections *a b c*, magnified figures (fig. 28.); and the cause of the floating of the body of the plant, or the leaf, as it may be termed, is rendered evident by the air cells of its cutis, and the two large air cells in its substance. These spongetlets of the capillary fibrils are the real nourishing organs of all plants; and as they are found only at the ex-

tremities of the rootlets, the reason is obvious why small plants thrive better close to trees which have parallel roots than at a little distance from them; the earth being less exhausted in the neighbourhood of the larger roots, than where the rootlets spread. It is a curious fact, that coloured fluids, which never pass through the cortical pores, pass readily into the spongetlets.

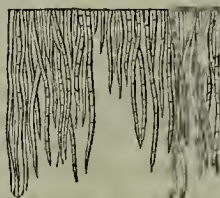
CHAPTER V.—Of the Structure of the Stem and Branches.

ALL stems, as far as regards structure, may be arranged into three classes:—

1. Stems which display, internally, an apparently homogeneous mass, inclosed in a simple cuticle.
2. Stems composed of bundles of vessels, apparent woody fibres, variously distributed in a cellular parenchyma, inclosed by a simple cuticle.
3. Stems composed of concentric layers of conjoined vessels, connected woody matter, surrounding a column of pith, and inclosed by a bark.

1. The stem, in the first of these classes, appears to the naked eye as if composed of interwoven fibres, forming a felt-like texture; but, when examined by the aid of a good microscope, these fibres are found to be oblong cells arranged parallel to one another, (fig. 29.)

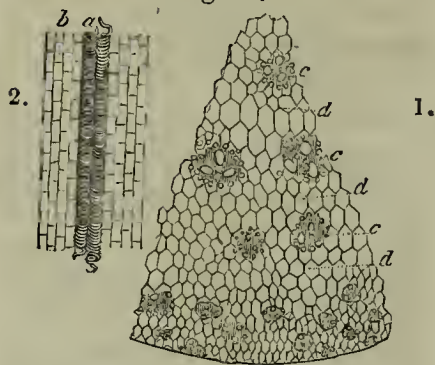
Fig. 29.



The Mushroom tribe (*Fungi*), the Lichens and the Flags (*Algæ*), afford the best illustrations of this description of stem.

2. The stems of the second class are composed of two distinct parts, a vascular or ligneous, and a cellular, variously arranged, according as the stem is solid or hollow. If we take the sugarcane (*Saccharum officinarum*), as an example of the solid stem of this class, we shall find it to consist of vascular cords (fig. 30., 1: *c c c*), interspersed in a cellular parenchymy (*d d d*), inclosed within an epidermis, which adheres closely to it. Both the cellular matter and the vessels are larger, and the vascular cords thicker and more distant from one another, in the centre of the stem than towards the circumference. The cells are short, hexagonal tubes, placed above one another: (fig. 30. 2. *b*, and fig. 4.) and each ligneous cord is composed of spiral or punctuated vessels, (see fig. 30. 2. *a*.) closely encircled with narrow oblong cells. In some instances,

Fig. 30.



the vascular cords run in straight lines; in others, they have a zig-zag course. In the knots of articulated solid stems of this description, the vascular cords send off branches, which meet and touch in arches before they are distributed to the leaf, which generally is given off at the knot, sheathing the basis of the new articulations. Stems of this class have no medullary rays. If they are *monocotyledons* (or plants whose seed has *one* seed lobe only), they increase in length, but, with the exception of the Aloes, Yuccas, and Dracena, never in breadth. The Palms, the stems of which are of this kind, all rise with a columnar stem, notched with the bases of fallen leaves, and terminated with a magnificent crown of foliage: and as the vitality of this description of plants depends on

the herbaceous part, if the terminating bud or cabbage, as it is termed, be cut off, the whole plant will immediately die. The White Lily (*Lilium candidum*) closely resembles the Palms in its development and growth. If they are *dicotyledon* (with *two* seed lobes), or *polycotyledon* (with *many* seed lobes) plants, the proportion of the cellular matter of the stem greatly exceeds that of the vascular. Thus, if we take white Bryony (*Bryonia alba*), as an example, we shall find that the stem consists of a mass of cellular matter, involving fourteen vascular fasciculi, and inclosed in a bark composed of a cuticle and three distinct cellular bands. See *a*, fig. 31. The cells are chiefly oblong hexa-

Fig. 31.

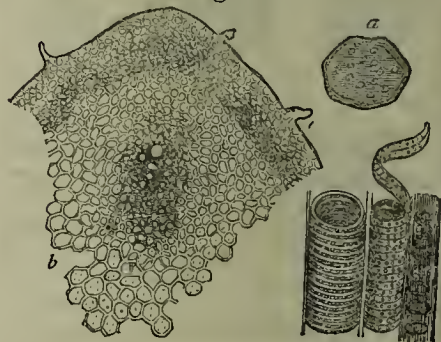


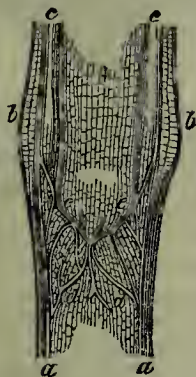
Fig. 32

gons, which are larger in the centre of the stem, (*b*, fig. 31.) and, as the season advances, become empty and almost resemble pith. The vascular bundles contain three distinct kinds of tubes; the *punctuated*, which is the largest and always in the centre; the *spiral*, with the fillet punctuated; and the *annular*, (see fig. 32.) Such is the general structure of herbaceous dicotyledonous stems of this class: they resemble monocotyledonous stems in having distinct fasciculi of vessels; but the presence of the bark is a sufficiently characteristic distinction.

In *hollow* stems of this class, the cavity is surrounded by a mass of hexagonal cells, involving fasciculi of vessels symmetrically arranged. If we take the Gourd as an example, we find ten fasciculi. The vessels vary in size and number according to the age of the stem: at first they are simple spirals; then some annular vessels appear; and, ultimately, they assume the character of the punctuated annular. In some plants, as Balsam (*Impatiens Balsamina*), the

vessels are spiral, annular and reticulated. The bark is cellular, and contains proper vessels. The cavity is in many instances interrupted at the knots (*nodi*) by a diaphragm; and it has been supposed, although with little truth, that each articulation may be regarded as a distinct individual, which takes its origin from one knot and terminates in another. If we examine the culm or stalk of Wheat, which is an articulated stem of this kind, we may perceive, by placing a longitudinal slice of one of the knots under the microscope, that the vessels of the lower articulation *a, a*, fig. 33, as soon as they reach the dia-

Fig. 33.



phragm, which separates the lower from the next articulation, give out the vascular cords *d, d*, which, traversing the diaphragm, rejoin the original cords in the leaf *b, b*; whilst the vessels of the new articulation *c, c*, seem to rise out of these, traversing the diaphragm *e, e*. There can be little doubt, therefore, that the articulated culm is one individual; for although the vascular cords of each articulation terminate in the leaf, yet the vessels of the new joint seem to be merely branches of that below it.

The Palms, Irises, Orchises, Grasses and Rushes, afford excellent illustrations of this description of stems.

3. The third class of stems, as has been already stated, is composed of three distinct parts, *bark*, *wood*, and *pith*. These are variously arranged, as the plants are woody or herbaceous.

The structure of the woody stem is exemplified in all trees and shrubs. If we take a transverse slice of any twig of the growth of one year, we find the *pith* in the centre inclosed by a ring of *wood*, and this surrounded by a circle of *bark*. If we take a longitudinal slice, we find another part, the *medullary rays*, trans-

versing the wood. The general structure of each of these parts has been already sufficiently described. A layer of bark and of vascular or woody matter, *albuminum*, is added every year to the diameter of the tree; and the functions of both the bark and the wood are chiefly carried on by these new parts, which are, therefore, whilst young, endowed with more irritability than any other part of the plant. Both the bark and the wood are formed from a gelatinous (jelly-like) secretion, named *Cambium*, which is deposited partly from the reducent vessels of the bark, and partly from the medullary rays, between the wood and the bark. It appears, however, to be principally prepared in the leaves and transmitted through the bark; for when the leaves of a tree or a shrub are destroyed, scarcely any new wood is formed in that season; and if the bark in the trunk of a tree be gnawed off by sheep, or otherwise removed, the portion of the wood above it continues to augment in diameter, because it is supplied with the elaborated, nutritious juices prepared in the leaves, while the portion below the wounded bark ceases to grow, owing to all communication between it and the foliage being cut off. See fig. 34.

Fig. 34.



Without prosecuting further this physiological discussion, it is sufficient to know, that it is from this elaborated sap that the new liber and albuminum are formed, by the organic power, or vital principle inherent in the plant, transforming this gelatinous fluid into cells and vessels, the diverging layers being formed at the same time as the concentric. Neither is it requisite, here, to inquire into the functions of the different kinds of vessels, which enter the composition of the concentric layers; we may only observe, that it is not yet ascertained, whether the simple spiral vessels transmit fluids; but there

is very little doubt that the punctuated vessels are those through which the sap is transmitted from the roots to the leaves. The layers of wood acquire hardness as they advance in age; but this is not the consequence of the mere loss of fluid parts, but of the deposition of woody matter, and other secretions in the cells; and this continues until the wood attain its final degree of hardness, which does not occur before the tree has arrived at its full growth. Hence the superiority of a tree felled at this time, to that of one cut down at any earlier period.

The *pith* is swollen with fluid, in the young twig or stem; but it becomes, afterwards, dry and spongy, and is slightly compressed by the swelling of the internal woody layer, during its process of hardening. The form of the pith is regulated by that of the cavity which it fills; and this, although for the most part circular, yet differs in different trees: thus, for instance, it is oval in the Ivy, furrowed in the Oriental Plane, triangular in Oleander, quadrangular in the Oak, and hexangular in Dogwood. It varies, also, in diameter in the same tree, even when young, being smallest at the base of the stem, larger in the middle, and smaller again at the summit; and these variations are observable in the growth of each future year.

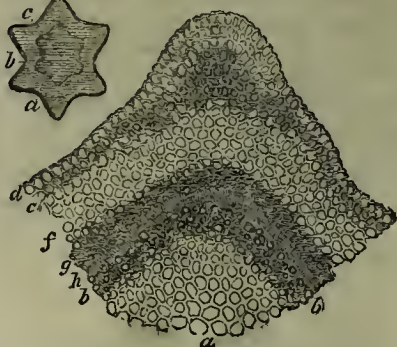
In most trees, the pith is entire and uninterrupted all along; but, in some, as the Walnut, it is intercepted by empty spaces (see *fig. 22.*); in a few, as the Magnolias, the column is broken by ligneous partitions; and in others, as Woodbine, it is merely a spongy sheath, lining the interior of the cavity of the stem and branches. Many conjectures have been hazarded respecting the use of the pith; it has been supposed to be the nervous system of plants, to give origin to buds, and to serve as a reservoir of moisture for the supply of the leaves, whenever an excess of perspiration requires it. But, it is most probably intended merely to afford the surface necessary for the formation of the first layer of wood; and to give, by the bulk of its swollen cells, a degree of firmness to the succulent stem and recent shoot, which they would not otherwise possess, before the bark and the alburnum require sufficient consistence for that purpose*.

The structure of Herbaceous stems of this class is well illustrated in the stem of Madder (*Rubia tinctorum*). In a transverse section, we find, 1, a bark, *a*, (*fig. 35.*) easily separated from

Fig. 35.



Fig. 36.



the parts beneath; 2, a vascular layer, *b*, somewhat resembling the first concentric woody circle in ligneous stems; 3, a cellular pulp, *c*, which gradually becomes dry, and assumes the appearance of pith. The bark is covered with a thin, transparent cuticle *d*, (*fig. 36.*) which transmits the colours of the green proper juice contained in the outermost layer of cortical cells *e*, immediately beneath it. Within this are several layers of hexagonal cells *f*, containing a pale yellow watery fluid, which deepens towards the interior of the bark, where we find its source, the proper juice, filling a range of narrow oblong cells, *g*, situated close to *h*, the layer of returning vessels. The outside vessels in *b*, which may be termed the ligneous layer, are large and punctuated; the inside are smaller and spiral, composed of three distinct filaments, and both are bedded in a green pulp. There are many modifications of this structure in herbaceous stems of this class; but chiefly in the arrangement of the vessels, which approaches more or less to that in ligneous stems. Thus, in the stem of Thorn-apple (*Datura stramonium*), which is an annual, the distribution and character of the parts so closely resemble those of trees and shrubs, that it may be considered a soft ligneous stem, demonstrating the great diversity, with respect to induration, in wood; whilst, in the Lettuce (*Lactuca sativa*), the sap-vessels are in distinct fasciculi, like those in the stems of the second class, but arranged in one circle; and the vessels in each fasciculus are disposed

* See Thomson's Lectures on the Elements of Botany, vol. i.

in diverging rays, separated by condensed cellular divisions.

But the most interesting circumstance connected with stems of this class is the origin of branches. When a bud protrudes to form a branch, the perpendicular vessels of the part on which it appears, separate to permit it to pass between them, and afterwards meet again (see *fig. 37.*), to pursue their original direc-

Fig. 37.



tion; a circumstance perfectly consistent with the fact, that branches are truly distinct individuals although attached to the parent; the lateral, or viviparous progeny of the stem, or of the older branches, on which they are produced. All branches proceed from germs formed in the earliest unfolding of the parts in which they appear, although the buds produced from these germs may not be protruded until the tree be greatly advanced in age. In the twig, yet inclosed in the bud, the rudiments, or germs of branches to be formed upon it, can already be perceived. It first appears as a simple vesicle, filled with a greenish fluid; apart from the permanent members of the plant, and enveloped by cellular tissue, filled with mealy particles. The organization gradually advances; and, if circumstances be favourable, the embryo branch becomes conspicuous in the spring, rising apparently, but not actually, from the medullary sheath of the parent twig, into the vessels of which the spiral vessels of the embryo branch open; and bundles of these are distributed to each of the new leaves, yet scarcely visible to the naked eye, and compressed within the scales of the bud. By degrees, the bud lengthens and swells; and, the scales giving way, the young branch is protruded, clothed with its leaves, each bearing in its bending the germ of a branch destined to become, in its turn, the parent of another series of branches. Let us pursue this investigation.

Before organization commences in the germ, the embryo branch is an insulated vesicle connected with the parent merely by cellular matter. The effect of the organic power is the addition of new matter to this living vesicle (or *punctum saliens*), and the evolution of new parts; till gradually extending in the direction of its axis, it unites with and becomes a permanent part of the parent plant. In the germ thus situated, and supplied with nutriment from the mealy granules contained in the cellular tissue surrounding it, the organization of the branch commences as from a centre. The first part which can be distinctly recognized is the pith; surrounding this, we next perceive lines which are the first traces of the spiral vessels of the future branch, running in a direction from the centre of the parent branch to the peak of the gem: indications of the separation of the cellular matter into scales are next perceptible: but the whole bud or gem is still a completely insulated body, and continues so until circumstances favourable to its complete evolution occur, however distant from the period of its formation. No determinate period, therefore, is fixed for the protrusion of the germ into a bud; but at whatever time this may happen, its course is traceable from the medullary sheath to the surface on which it appears, by a pale stream of parenchymatous matter traversing each annual, concentric, ligneous layer (see *a a, fig. 38.*) But this parenchymatous track

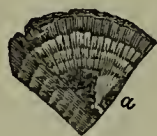
Fig. 38.



only marks the advancement of the vital speck or germ to the surface of each annual belt of wood; and is altogether useless as far as regards the germ, except in the belt, on the surface of which it is seated; with the life of which, indeed, its vitality is intimately

connected. Destroy this, and the germ becomes extinct (see *a*, *fig. 39.*); augment its vital energy, and the germ is

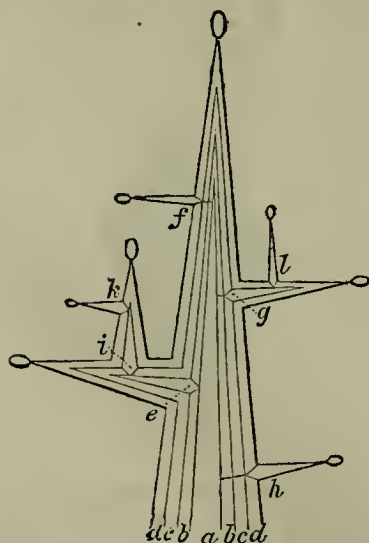
Fig. 39.



unfolded into a perfect bud and branch, but leave things as they are, and the germ will advance to the surface of the next year's belt of wood; and so on progressively, until it be ultimately unfolded, or perish with the destruction of the tree. The twig, therefore, which appears on the surface of an old hollow trunk, is still to be regarded as having originated in the first year of the growth of that part of the trunk, however old it may now be, and its progress is traceable through the shell of wood, which still remains free from decay.

A very clear idea of the origin and connection of branches may be conveyed by the aid of a figure. Thus, if we imagine the successive years of the growth of a tree to be represented by the cones *a*, *b*, *c*, *c*, and *d*, *fig. 40.*, it is evident that the germs furnishing the branches *e f g h*, although all generated on the surface of *a*, in the spring of the first year, are, nevertheless, un-

Fig. 40.

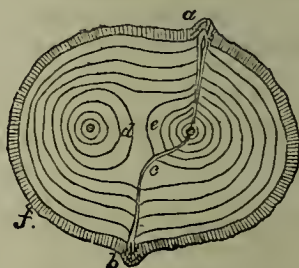


folded at different periods of the growth of the tree. In the first year, *e* only becomes a branch, on the surface of which *i* is generated; which in its turn

generates *k*: in the second year *g* is unfolded and generates *l*: the third year brings forth *h*, and the fourth *f*. In these branches the age of each is clearly indicated, from *g*, which is one year old, to *e* which is four: but although this is the case, and *f*, which has sprung from an apparently adventitious bud, is not older than *k*, a secondary branch from *e*, yet the germs of all were generated on *a*, and consequently of the same date with the first developement of the trunk.

It is a curious fact, not generally known, that the germ, if not yet unfolded, will not advance through any belt of wood, not actually belonging to the stem on which it originated, however intimately connected with it; or that the specific action necessary for perpetuating the germ, cannot be begun in any one of a succession of concentric circles, when it has not originated in the first of the succession. Thus, in the section of the trunk of a willow, represented in *fig. 41*, cut a little below the

Fig. 41.



joining of two branches that have grown together into one, we find the bud *a* moving onwards in a direct line from the centre of the trunk; but *b*, as soon as it touches the belt *c*, where the coalition occurs, turns aside; and, instead of being protruded at *f*, appears at *b*. In this section, *d* marks the last independent belt of the branch, and *e* that of the trunk: the other zones, common to both, are the result of alburnous matter furnished by each in particular.

It is proper to remark, that the foregoing theory of the origin of branches differs from all those usually received; and in particular is at direct variance with the opinion of Du Hamel, supported by Mr. Knight, that every alburnous layer is capable of giving origin to buds and branches. But the truth of it is demonstrated in every bud and branch,

in a state of natural growth; and, although a bud may be artificially produced from any layer of alburnum, yet, such is not the course of nature. As far as regards the origin of branches, therefore, the following conclusions may be safely adopted.—“1. That every branch originates in a germ. 2. That every germ is a distinct, insulated individual, the lateral progeny of the plant, generated at the period of the development of the stem or the branch on which it appears as a bud. 3. That every adventitious bud, or bud appearing on an old stem or branch, originates in a germ generated at the development of the stem or branch on which it appears, however long it may have remained latent. 4. That every latent germ is, annually, carried outwards in a horizontal direction through every concentric layer of wood, intermediate to the pith and the surface on which it shall sprout into a branch, leaving behind it a white mark crossing every ligneous belt, by which its progress can be traced. 5. That every branch when fully developed displays the same structure as the stem.”

CHAPTER VI.—*Of the Structure of Leaves—in the unexpanded State—in the expanded State—Cuticular System.*

THE leaf, generally speaking, is a temporary part of the plant, originating at the same time as the branch of which it forms an appendage, flourishing during spring and summer, and perishing towards the close of autumn. Some plants, however, preserve their leaves through the winter; and even those the leaves of which fall in autumn, are not, strictly speaking, devoid of leaves in winter, for the new leaves are already formed and inclosed in small pyramidal bodies, either seated on the surface of the sides of the branches or terminating them. In examining leaves, therefore, we have to regard them in two conditions; as inclosed in the bud, and as freed from it in an expanded state.

1. *Leaves in their unexpanded state.* The pyramidal bodies in which leaves are contained during winter, are termed buds or gems (*gemmæ*), and from their office, *hybernacles*, or winter habitations (*hybernacula*). Whatever may be the exterior form, or the position of the bud on the branch, the leaves within it are

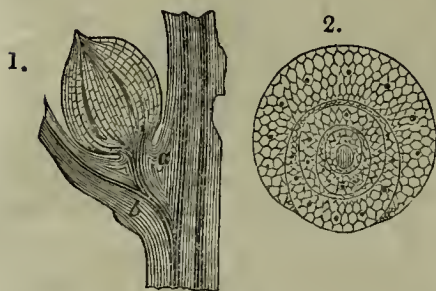
folded up, or applied to one another, in such a manner as to occupy the smallest possible space. The young shoot within its hybernacle is the progeny of the plant; and, if removed from the parent and grafted upon another tree, or planted in the soil, under favourable circumstances, will grow and become a tree closely resembling the parent. In this case, however, the graft and the tree raised from the planted gem, are mere extensions of the parent, not new individuals, as if they were raised from seed.

Botanists notice four distinct kinds of buds; but two only of these can be regarded as Hybernacles; the *Bulb* (*bulbus*), which spontaneously separates from the parent plant; and the *Bud* or *Gem* (*gemma*), which remains attached to it. The other two, the *Propago* and the *Gongylus*, do not even inclose leaves. The former, the *Propago*, consists of cellular tissue, is of no regular shape, and is only sometimes covered with an epidermis. It separates spontaneously from the plant. Many of the less perfect plants, the Lichens and the Algæ, are propagated chiefly by the *Propago*. The latter, the *Gongylus*, consists also of cellular tissue, like the *Propago*; but it is firmer and of a solid consistence, and is always covered with an epidermis. It is attached to the parent under the bark, and separates spontaneously only when this decays.

The *Caulinar Bulb*, or *separating Hybernacle* (*Bulbus Caulinus*), is a cellular body, in some instances pyramidal, in others of a globular shape, composed of scales, which are either concentric or overlap one another. The Bulb, although here termed caulinar, yet is also an appendage of roots. When it is produced on the stem, it usually appears in the axillæ of the leaves, and can sometimes be observed as a white speck there, long before the leaves expand. If we take a Bulb from the stem of the Orange Lily (*Lilium bulbiferum*), as an example of this species of Hybernacle, and cut it across, we find that it consists of cellular scales embracing one another, as represented in the section *fig. 42*, 2. and inclosing fasciculi of vessels, which appear as dark points in the transverse section. The cells are filled with mealy grains, mingled in a thick fluid, which diminishes in opacity as it approaches the centre of the bulb. Each scale is covered with a beautiful, easily detached epidermis.

In the longitudinal section of the bulb in situ, (*fig. 42, 1.*) we perceive that

Fig. 42.



converted into leaves; whilst in others, as the Rose, they are converted into the *petioles*, or foot-stalks of the real leaves, which spring out of them.

The origin of Gems has already been fully explained, and the truth of that theory is proved by the examination of the terminal gems of trees, those which carry on, as it were, the original line of stem. In the terminal gem of Horse-Chesnut, for instance, examined in the autumn, the pith is found to be completely terminated at the base of the bud, as seen at *a* (*fig. 43.*); and, in

Fig. 43.



the following spring, although the pith of the new shoot touches it, yet, it is evidently not a continuation of the old, but a distinct production of the gem, and is continued downwards until it meet the old, at the point *a* (*fig. 44.*),

Fig. 44.



the section of a bud opened and the young shoot advancing.

The *Bud*, *Gem*, or attached hybernacle (*Gemma*), consists of the young shoot and the inclosing scales, which, strictly speaking, form the hybernacle, being intended to protect the tender shoot in winter from the action of the atmosphere and of light. Some buds, even on the same tree as those already mentioned, inclose leaves only; others inclose flowers only; and some inclose both leaves and flowers: each kind is distinguishable by its external form, and according to its contents is named *foliifera*, *florifera*, and *mixta*, as it bears either leaves, or flowers, or both. In their organic structure, the scales of gems resemble those of bulbs, being composed of cellular tissue, with distinct fasciculi of vessels running through it; and this separation of the vascular fasciculi is the feature which distinguishes these scales from leaves. The inner scales perform the functions of leaves, until these are perfected and fully expanded, when they drop off; but in some trees, as the Apple and the Almond, they are

The buds of trees, being in a state of great sensibility, feeling the first warmth of the sun, the vitality of the continued shoot is roused into action; it attracts the moisture contained in the neighbouring cells charged with nourishing matter; the rising sap, also, enters its vessels; it gradually swells, and bursting the inclosing scales, pushes into the light and air, unfolding its leaves successively as it advances, until the whole

tree becomes green. It should be remarked, however, that the terminal gems open sooner than the lateral, owing, most probably, to the current of the sap being more direct towards them, and its impulse consequently greater.

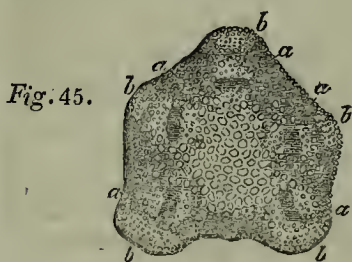
2. *Leaves in their expanded state.* Much of the beauty and interest of the vegetable kingdom depends on leaves, whether we regard them as the clothing of single plants, or of groups. To the plants themselves, they are the most important of the conservative organs, performing nearly the same function in the vegetable economy, which the lungs perform in that of the animal.

Every leaf consists of two parts; the one thin and expanded, in ordinary language, the leaf (*folium*); the other as thick as it is broad, the footstalk or petiole (*petiolus*): these together constitute but one organ or proper leaf; and, with a few exceptions, when the leaf falls, it always separates from the twig at the base of the petiole. Leaves are more diversified in form and composition than any other of the vegetable organs: they are simple and compound; differ in situation and distribution on the branches; in direction and insertion; in respect of expansion, point or apex, base and margin; in surface, substance, composition, and appendages. In size they differ as widely: the leaves of *Hypnum trifarium* are almost microscopic objects, while those of the Talipot Palm (*Licuala spinosa*) have been known to exceed thirty feet in circumference. Leaves are either *caducous*, falling before summer is passed; or *deciduous*, falling in autumn; or *persistent*, not falling until pushed off by the new leaves, in the following spring; or *perennial*, of still longer duration.

Leaves are composed of three textures; a vascular, a cellular, and a cuticular tissue: and we expect to find these parts in the midrib and nerves, the parenchyma, and the surfaces of every leaf. When means, whether natural, as the atmosphere, and the moisture contained in it, or artificial, as steeping in water, and exposure to the air, are employed to destroy the cuticle and the parenchyma of leaves, the fasciculi of vessels which constitute the ribs and nerves, as they are improperly called, remain, and constitute what is termed a skeleton leaf. In skeleton

nerves, running either in straight lines from the midrib to the margin, or branching off in an infinity of divisions, so as to produce the appearance of a reticulated web. On a more close examination, we find that these ribs (*costæ*), whether straight or reticulated, consist of fasciculi of conducting vessels, closely accompanied with proper or returning vessels. In those leaves, the ribs of which run in straight longitudinal lines, the fasciculi constituting these are united by transverse vessels, at certain distances, which are not given off from the fasciculi, as Grew and others have supposed, but are distinct vessels, united with the fasciculi by insertion. In thick and succulent leaves, as those of Aloe, thick cords of spiral vessels, accompanied by large bundles of proper vessels, separated only by a thin layer of cellular substance, are observed to traverse the leaf. This leaf is bordered by spines, into which cords of spiral vessels pass, given off from the fasciculus nearest to them. In leaves, in which the *costæ*, or ribs, are transverse, the same communication between the *costæ*, by inosculating, or uniting vessels, occurs, forming rhomboids; and this structure is common to all monocotyledonous leaves (or leaves of plants whose seed has one seed-lobe). At the point of attachment, between the branch and the petiole, if this be dilated, the vessels enter the petiole in distinct fasciculi, the number varying in different plants. The sap and the proper vessels are closely attached in the same fasciculus whilst in the leaf; but they separate at the point of attachment, the sap vessels passing from the medullary sheath of the twig into the leaf, and the returning vessels passing from the leaf into the bark of the twig.

The arrangement of the vessels varies in different petioles:—thus in a transverse section of the footstalk of a leaf of Elder (*Sambucus nigra*), we find that there are five distinct, compound fasciculi of vessels, *a a a a a* (fig. 45.),



and five of reductent vessels, *b b b b b*, immediately within the cuticle; one of the compound fasciculi passes into each leaflet, and, therefore, the number is determined by that of the leaflets. In the petiole of Kidney Bean (*Phaseolus nanus*), however, which is composed of moveable articulations in order to enable the leaf to close at night, the fasciculi are collected into one fasciculus in each of the articulations, or joints, as represented at *a* (fig. 46.);

Fig. 46.

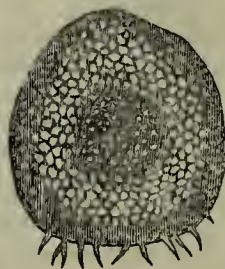
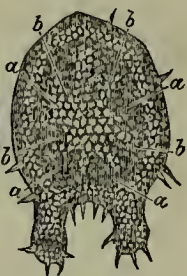


Fig. 47.



while they form a circle, *a a a*, (fig. 47.), surrounding wedge shaped fasciculi, *b b b b b*, immediately under the bark in the channelled part of the petiole. The advantage of this vascular arrangement is obvious; for had the fasciculi remained distinct, surrounding the pith in the articulations, those on the outside of the flexure, in the movement of the joint, must have described a circle of an extent to endanger the vessels by stretching them, and those on the inside would be equally injured by compression; but being collected in one fasciculus, in the centre of the moveable part of the petiole, every movement can be borne with impunity. In the distribution of the vessels, in the divisions and secondary divisions of the midrib, it appears that the whole are separations from the petiolar fasciculus or bundle of the leaf-stalk: but the single vessels connecting these are evidently not separations from the larger fasciculi. There are much fewer vessels in succulent than in membranous leaves, less fluid being conveyed from the roots of the plant; owing to the leaf perspiring less, and absorbing much to supply the deficiency from the root.

With regard to the cellular structure, all leaves are chiefly made up of cellular tissue. The cells present a variety of forms, as they happen to be more or less compressed; but the prevailing forms are the globe and the hexagon.

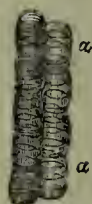
In all leaves, the cells, immediately under the cuticle of the upper surface, differ from those next the lower. If the leaf of Christmas Rose (*Helleborus niger*) be selected to illustrate this difference of structure in the same leaf, we shall find a range of tubular cells, which terminate in the pulp of the leaf, immediately under the cutis of the upper surface; while those next to the lower disk are irregular hexagons (fig.

Fig. 48.



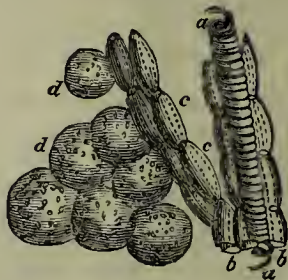
48.) The most singular cells are those of the Moss, called *Spagnum obtusifolium*, which exhibit spirals, as if open spiral vessels, *a a*, fig. 49. On the under side

Fig. 49.



of every leaf the cellular matter is less compacted, and many vacant spaces are found between the cells. The individual cells are transparent membranous vesicles, placed in contact with one another, or with the vessels, as represented in the greatly magnified morsel of the pulp of *Cactus flabelliformis* (fig. 50.); *a a*

Fig. 50.



a spiral vessel, *b b* beaded vessels, *c c c* a branch of beaded vessels, and *d d* the cells. Air repositories are present in the leaves, as well as the stems of aquatic plants; and the partitions or diaphragms separating these repositories are, in some instances, singularly constructed,

But the most interesting part of the leaf, is its cuticular system. Every leaf has a cuticular covering, which is composed of two distinct parts: 1. the *epidermis*, which forms the exterior covering of the leaf, in common with every other part of the surface of the plant, adhering firmly to the cutis below it, and entering into every pore; 2. the cutis, which consists of a vascular network, laid upon a layer of air-cells. The nature of the *epidermis* has been already explained, and it does not differ in the leaf; we shall, therefore, confine our attention to the *cutis*. The vascular network, which forms one part of this organ, is made up of lymphatic vessels,

the meshes of which assume various forms in different plants; but maintain always the same form in the same plant. A powerful microscope is requisite for ascertaining the following particulars. In plants, the leaves of which have parallel costæ, these meshes are irregular parallelograms, as in Spiderwort (*Tradescantia*); sometimes the vessels are slightly undulated, as on the leaf of the White Lily (*Lilium candidum*), (fig. 51); or zig-zag, as on that of Indian Corn (*Zea Mays*), (fig. 52). The meshes sometimes form truncated lozenges, as in common Meadow Grass (*Poa trivialis*); in some fleshy leaves they form nearly regular hexagons,

Fig. 51.

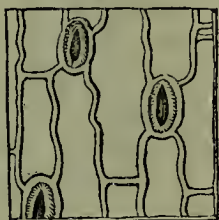


Fig. 52.

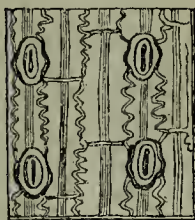
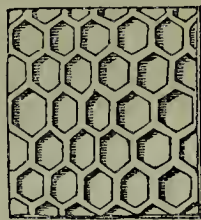


Fig. 53.



as on the upper disk of the leaf of *Hoya carnosa* (fig. 53), and on both surfaces of that of *Aloe verrucosa*; but in general they assume very irregular forms. Over the larger vascular fasciculi they invariably appear as irregular parallelograms, whatever may be their form on the other parts of the leaf. The size of these meshes differ in different plants; they are always larger than the diameter of the cells of the parenchymatous part of the leaf; but, in some plants, they are so minute, that 55,296 are contained within a square inch of surface. This cuticular layer is perforated with organic pores or slits (*pori corticales*) which, as they perform a most important function in the vegetable economy, shall be examined a little in detail.

The organic pores of leaves were first noticed by Grew: they have since been more particularly investigated by Hedwig, Rudolphi, Link, Keiser, and De Candolle, who examined them in six hundred plants. We have ourselves attempted to arrange them, and to ascertain their external structure. They are found on the inferior surface or disk of the leaves of trees and shrubs; on both surfaces of those of almost all the herbaceous plants, the Grasses, the Coronariæ, or liliaceous plants, and the Palms. In aquatics, the leaves of which float on the water, the upper surface

only is furnished with pores; but leaves which are wholly under water have no pores, although the leaves which are in the air of the same plant have them. Plants destitute of leaves, such as some of the Cactus tribe and the Rushes, are furnished with these pores on the stem; they are found also on the foliaceous parts of the flowers, as the Calyx, and on some seed vessels of a leaf-like structure, as for instance the pod of Bladder Senna (*Colutea Senna*). These organic apertures vary in form, size, and number.

As far as regards *form*, they may be arranged under six species.

1. A simple slit, more open in the middle than at either end, bisecting an oval shield. It may be named the *oval scutiform aperture* (*Osculum scutiforme ovale*), fig. 54, as exemplified on the

Fig. 54.



Fig. 55.



under disk of the leaves of Sage (*Salvia*), Holyhock (*Alcea*), the Chesnut (*Fagus*), Horse-Chesnut (*Æsculus*), Laburnum (*Cytissus*), Oak (*Quercus*), Sumach (*Rhus*), Rhododendron *Ponticum*, Aristolochia, *Sipho*, Walnut

(*Juglans*), Pear (*Pyrus*), Vine (*Vitis*), *Cobea Scandens*, *Philadelphus Coronarius*, *Vaccinium Stamineum*, Poplar (*Populus*), &c.: in the upper disk of the leaf of Palmated Rhubarb (*Rheum palmatum*); and in both surfaces of the leaves of *Plantago Vulgaris*, the Broad-Bean (*Vicia faba*), Spinach (*Spinacia*), *Aster Trifolium*, *Mentha Trifoliata*, and many other herbs. In *Acuba Japonica*, the shield is divided into four portions. See fig. 55.

2. A simple slit bisecting an oval shield, enclosed within a ring:—the

Fig. 55.



Fig. 57.

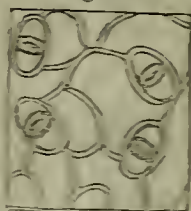


Fig. 58.



the upper disk of the leaf of Sorrel, *Rumex Acetosa*; and on both surfaces of that of the White Lily (*Lilium candidum*), *Amaryllis*, *Rudbeckia*, Common Cabbage (*Brassica oleracea*), *Alisma Plantago*, *Caltha Palustris*, *Iris*, &c.

3. An open slit, or oblong pore, within a simple oval ring:—the oblong annulated pore (*osculum annulare oblongum*), fig. 59. It is exemplified on the under disk, in *Hibbertia Scandens*, Ivy (*Hedera*), Wolfsbane, *Aconitum Neomontanum*, Spearmint, *Mentha Viridis*, Elder, *Sambucus Racemosa*, Cabbage Rose, *Rosa Centifolia*, Official Rhubarb, *Rheum Palmatum*, Mezereon, *Daphne Mezereum*, Lilac, *Syringa Vulgaris*, the Clove-pink (*Dianthus caryophyllus*), *Laurus Canariensis*, the Privet (*Ligustrum*), &c. On both surfaces in Wild Spinach, *Chenopodium*, Saxifrage, Dragon Arum, *Dracontium*, African Geranium, *Pelargonium*, Everlasting Pea (*Lathyrus latifolius*), Mistletoe (*Viscum*), Fennel (*Anethum fœniculum*), although it has not an ex-

Fig. 59.



Fig. 60.



panded leaf, and Glass Wort, *Salicornia*, although it is twice a day under water. The Scented Violet (*Viola odorata*),

annulated scutiform aperture (*osculum scutiforme annulare*), fig. 56. Examples of it are seen in the under disk of the leaves of Fœtid Hellebore (*Helleborus fœtidus*), the Coffee plant (*Coffea*), Peony (*Pœonia*), Mulberry (*Morus*), the Olive (*Olea*), *Gardenia Latifolia*, the genus *Theophrastus*, the outside of the tubular leaf of *Sarracenia*, &c.

In *Gœrtneria*, the shield lies, as in fig. 57, across the oval of the ring: in *Jacquinia Russicifolia*, it is circular, and the slit bisecting it is extended beyond it (fig. 58). It exists, also, on

has a double oval, with the outer one quartered, as in fig. 60.

4. A circular pore, in the centre of a circular shield:—the circular scutiform aperture (*osculum scutiforme circulare*), fig. 61. a. It is observed on the under disk of *Hydrangea Quercifolia*, Great Flowering Saint Johnswort, *Hypericum Grandiflorum*, *Cambretum*, &c.; on *Pettispora Tubera*, (fig. 61. b.), the shield is divided: on the upper disk of Holly-hock (*Alcea*), and Sorrel (*Rumex acetosa*), and on both surfaces in *Cactus Opuntia*.

Fig. 61. a.



Fig. 61. b.



5. A circular pore, enclosed in a ring: the annular pore (*osculum annulare*), (fig. 62.); as exemplified on the under disk, in Aloes, the Air-flower (*Epidendrum*), Primrose (*Primula*), &c. In *Cussonia Thyrsifolia*, the circle is divided in quarters, as in fig. 63. It is seen in both disks in Aloes.

6. A quadrilateral pore (*osculum quadrilaterale*), as on both disks in *Agave Americana* (fig. 64). The modifications of these species of the cuticular aperture are very numerous; and, as the subject has been hitherto very little investigated, many new species may yet be discovered.

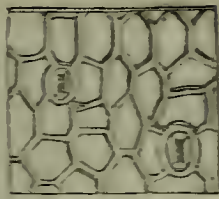
Fig. 62.



Fig. 63.



Fig. 64.



In respect of *size*, these apertures differ greatly in different plants. The largest yet seen are found in the under side of the leaves of *Oleander* (*Nerium Oleander*): it is a simple oval aperture guarded by hairs, which cross the opening in every direction. The smallest are found on the leaves of the Genus *Myrtus*. In the *Coronariae*, their longitudinal diameter, according to Springel, is from $\frac{1}{3}$ to $\frac{2}{3}$ of a line; their diameter in a cross direction, from $\frac{1}{4}$ to $\frac{1}{3}$ of a line.

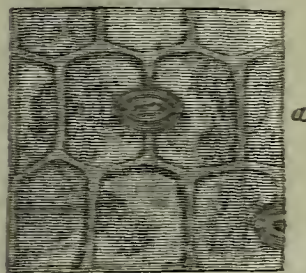
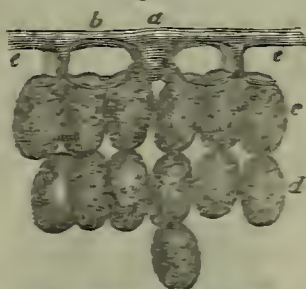
In number the difference is still more remarkable. The following tabular statement has been drawn up from actual observation.

Names of the plants on the leaves of which the pores have been counted	Number of pores on one inch square of surface.		
	On upper disk.	On under disk.	On both.
<i>Andromeda spiciosa</i>	None	32,000	
<i>Arum dracontium</i>	8000	16,320	24,320
<i>Alisma Plantago</i>	12,000	6000	18,000
<i>Amaryllis Josephiana</i>	31,500	31,500	63,000
<i>Cobea scandens</i> ..	None	20,000	
<i>Dianthus Caryophyllus</i>	35,500	28,500	77,000
<i>Daphne Mezereum</i>	None	4000	
<i>Epidendrum</i>	None	4800	
<i>Hypericum grandiflorum</i>	None	47,800	
<i>Hydrangea quercifolia</i>	None	160,000	
<i>Gæneria</i>	1000	142,750	143,750
<i>Ilex</i>	None	63,600	
<i>Iris Germanica</i> ..	11,572	11,572	23,144
<i>Olea Europea</i> ..	None	57,600	
<i>Peonia</i>	None	13,700	
<i>Pentstemon tuberosa</i> ..	None	160,000	
<i>Philadelphus coronarius</i>	None	20,000	
<i>Pyrus</i>	None	24,000	
<i>Sempervivum tectorum</i>	10,710	6000	
<i>Syringa vulgaris</i> ..	None	160,000	
<i>Rheum palmatum</i> ..	1000	40,000	41,000
<i>Rudbeckia</i>	8000	41,000	49,000
<i>Rumex acetosa</i> ..	11,088	20,000	31,088
<i>Theophrastus</i> ..	None	172,032	
<i>Tussilago farfara</i> ..	1200	12,500	13,700
<i>Tradescantia</i>	2000	2000	4000
<i>Vitis vinifera</i> ..	None	13,600	
<i>Viscum album</i> ..	200	200	400

On the leaf of *Gardenia latifolia*, we find a pore in almost every mesh; on that of *Aloe Socotrina* one pore for every twenty meshes, and on that of *Nerium Oleander* one for every sixty.

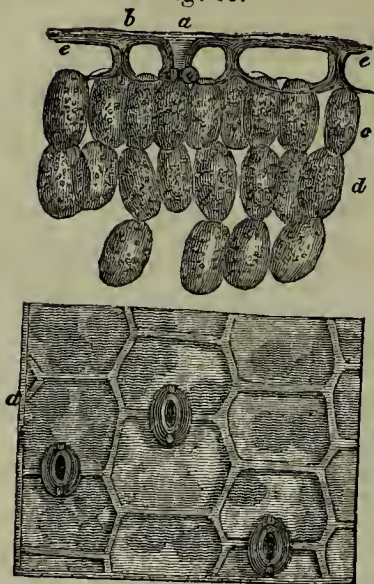
Such are the circumstances connected with the superficial state of these pores. The real nature of their structure can only be known by placing, under a powerful microscope, a thin slice of any leaf cut in the direction of its thickness, and bisecting one or more of its pores. The leaf of the Clove Pink (*Dianthus Caryophyllus*), is well adapted for this purpose. In the slice represented in fig. 65, the pore *a* is divided longitudinally

Fig. 65.



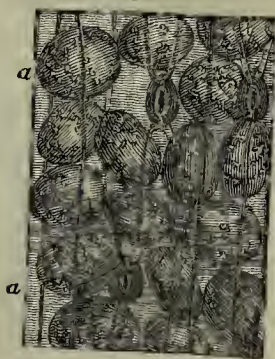
and in fig. 66 transversely: it is a short funnel-shaped tube, penetrating the cutis *b*, and surrounded at the bottom with a hollow ring: and opening into the intercellular spaces formed by the parenchymatous vesicles *c d*, &c., not pressing closely upon one another. These vesicles are distended with a greenish fluid, interspersed with mealy grains. Surrounding the pore, the oblong cells *c c* are evidently cuticular air-cells, and correspond to the meshes

Fig. 66.



formed by the lymphatics on the surface of the leaves. This explanation also refers to *fig. 66*, in which the pine is cut across in its narrow diameter. This form of the cuticular aperture varies in the leaves of different plants; but the general character is nearly the same in all. This is well illustrated in the portion of the inner surface of the cutis of *Iris Germanica* (*fig. 67.*), in which not only the pore

Fig. 67.



is modified, but the intercellular spaces *aa*, under the pores, are considerably larger than those of *Dianthus*.

M. Bonnet, Sprengel, De Candolle, Mirbel, and many other justly celebrated phytologists, regard these pores as merely absorbing and exhaling organs. It is not easy to conceive how the same aperture should perform such opposite functions; and a closer investigation has proved that they do not absorb. That they are the foliar exhalants is

demonstrated by the following facts:—Aqueous transpiration is greatest in those leaves which have most pores*. Plates of glass, applied to the under sides of the leaves of trees, are soon covered with drops of water; but when applied to the upper surface, they are not bedewed. When the under surface of the leaves of trees is varnished, so as to obstruct the pores, no transpiration takes place. Facts and experiments, equally conclusive, prove that they are not absorbing organs. Thus, leaves which are fleshy and succulent, and which are scarcely, if at all, nourished by the roots, but chiefly by absorption, have very few cuticular pores. None are found on the under surface of floating leaves, but the upper is thickly covered with them; yet it is well known that these leaves absorb powerfully by the under surface, and exhale by the upper.

But is exhalation the sole function of these foliar apertures? It is out of place to enter fully into a physiological discussion, while we are engaged in explaining the vegetable structure; but we have no hesitation to state, briefly, the grounds of our belief, that beside being exhalants, these apertures are the respiratory organs or lungs of plants. In the *first* place, these apertures are found only on leaves which are exposed to the action of the air; and even leaves, which are not naturally under water, soon lose them if they are covered with water. In the *second* place, thin, membranous leaves moveable in the air, are most liberally supplied with these apertures, owing to their probably requiring, like the more perfect animals, a constant supply of atmospheric air; while those which have thick, immoveable leaves, as they resemble the slow-moving and cold-blooded animals in their tenacity of life, so like them, also, require a smaller supply of air, and are, consequently, less liberally furnished with breathing apertures. In the *third* place, these apertures are admirably adapted for admitting air into the substance of the leaf, to bring it into contact with the juice contained in the cellular vesicles, for the production of those changes which the sap is known to undergo in the leaves, and which cannot

* *Hydrangea quercifolia*, which perspires so freely that the leaves wither and become crisp in a very short space of time, if the plant be not amply supplied with water, has 160,000 apertures on every inch square of surface, on the under disk of the leaf.

be supposed to depend wholly on exhalation. The minuteness of these apertures renders it difficult to ascertain whether they have the power of opening and shutting; but from their appearance on the leaf of Indian corn, *Zea mays* (fig. 68.), and on that of Iris

Fig. 68.



Fig. 69.



manica (fig. 69.), highly magnified, it is not improbable that some degree of dilation and contraction of the orifice takes place, although the fact cannot be demonstrated.

From the examination of their structure, the importance of leaves in the vegetable economy may be readily conceived. The sap is carried into them by one set of vessels; is there spread out and exposed to the action of air and light, and exhales its superabundant water; and having undergone by the influence of these agents, aided by an electro-chemical power, certain changes in chemical composition, it is received into another set of vessels, in order that it may be conducted downwards and distributed in the cortical cells, depositing there the various secretions requisite for the nourishment, health, and preservation of the stem and root. The cuticular system of the leaf is admirably adapted to aid these processes; by its transparency, its vesicular texture, and its respiratory pores. But the leaf itself is, also, a secreting organ, and retains in its cells many secretions, useful undoubtedly to the plant itself; but independently of it, of the first importance to Medicine and to the useful Arts, and in supplying food for the support of animal life.

CHAPTER VII.—Of the Structure of the Appendages of the Conservative Organs—Scales—Suckers—Tubers—Radical Bulbs—Glands—Pubescence—Thorns—Prickles—Props—Foliaceous Appendages.

THERE are certain organs attached both to roots and stems, which as they are

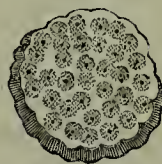
not general, are not classed with the common members of the vegetable body: these are named *Appendages*. A brief description only of each is requisite.

1. **SCALES** (*squamæ*) are generally found on roots, as, for instance, on the root of Toothwort (*Lathræa squamaria*). They consist entirely of cellular tissue, enclosed in a cuticle.

2. The **SUCKER** (*Stolo*) is an underground bud, sprouting from the upper horizontal branches of the roots of trees; and rising above the soil, it is converted into a stem resembling the parent-tree. Its organization is exactly the same as that of the leaf-bud.

3. The **KNOB** (*Tuber*) is a solid, massive body, attached either closely, or by means of a vascular cord, or wire as it is usually termed, to the base of the stem of some plants: it is also sometimes produced on the stem. The tuber varies greatly in form and appearance; but it has, in every instance, nearly the same structure, and consists of a cellular parenchymatous mass, covered with an epidermis devoid of apertures, and furnished with vascular fasciculi, which either surround the central mass of cells, or are distributed through it, according as the plant which bears the tuber originates from seeds with one or with two cotyledons (or seed-lobes). Thus, in the Orchis tribe, which is monocotyledonous, the vessels are distributed as in the Palms, represented in the transverse slice of a tuber (fig. 70.); while in

Fig. 70.



the tuber of the Potatoe, which is dicotyledonous, the parenchyma is bordered with a complicated circle of vessels, which has a close affinity to the cortical part of the stem. The vessels, in both instances, are collected at one or more points on the surface, wherever the embryo of a bud or gem is seated. The cells are filled with mealy grains; for tubers are merely reservoirs of nourishment for the young plants on their surface, which resemble the plantule in seeds, and are endowed with the same vitality, remaining latent until the tuber be placed under circumstances.

favourable for vegetation. The vascular cords which connect the tuber with the plant which forms them, resemble the umbilical cords (or navel strings) in animals, and decay as soon as the tuber is fitted to maintain a separate existence.

4. **RADICAL BULBS** (*Bulbi radicales*) are like tubers, reservoirs of nourishment for aiding the developement, and the temporary support of the lateral progeny of a certain class of plants. They are *solid*, *scaly*, and *laminated* (or compounded of plates). In internal structure, the *solid* bulb resembles the monocotyledonous tuber. The organization of the *scaly* bulb attached to roots is nearly the same as that of the caulinar (or stalk) bulb: each scale is a distinct reservoir of nourishment, and appears, also, to possess a distinct vitality; for when detached from the bulb, and placed in a proper soil, a new bulb or bulbs form on its edge, although nothing of this kind occurs when the scales remain attached to the general bulb. The *laminated* bulb differs from the *scaly* in external character only. In both, the scale and the layer consists of a plate of cellular substance enclosed between two thin half-transparent cuticles, with equidistant fasciculi of spiral and entire vessels running vertically through them.

5. **GLANDS** (*Glandulæ*): the real existence of bodies which exactly merit this appellation in the vegetable system, is doubtful. There are, however, minute organs, differing in structure from the common texture of the part where they are situated, which separate some peculiar matter from the ordinary proper juice, and which may be regarded as glands. If this be admitted, these glands occupy the interior and exterior of stems and leaves, vary greatly in form and attachment, and perhaps in structure, although any attempt to demonstrate that can scarcely be depended upon.

Internal vegetable glands are generally seated in the substance of leaves, with a small excretory duct or channel. These furnish the little drops of essential oil found in many leaves, as, for instance, that of the Black Currant. In some leaves, when the cells are swelled with fluid, these ducts are pressed upon and closed, so that the leaf exhales no odour, although a powerful odour is exhaled as soon as the withering of the leaf opens the ducts. This is the case in sweet-scented Meadow Grass (*Ar-*

thoxanthum odoratum), whence new hay derives its odour.

External vegetable glands are either (*sessile*) without foot-stalk, or (*pedunculated*) having a foot-stalk. The first exhibits the form of Papillæ (*fig. 71.*), as found on each side of the midrib of *Passiflora lunata*; or of detachable scales, covering a papillary gland (*fig. 72.*), as in *Rhododendron punctatum*. The second exhibits various forms. Thus on the foot-stalk of the leaf of the Nectarine (*Amygdalus Persicus*), it resembles a shallow cup, supported on a thick, short *pedicel*, or stand, with the cavity which exudes the secretion devoid of epidermis (*fig. 73.*); in *Ricinus communis*, it resembles a small round-headed nail (*fig. 74.*), and in this, also, the exuding surface is bare. On the upper disk of the leaf of Sundew (*Drosera rotundifolia*), it is a cup-shaped gland supported on a slender stalk (*fig. 75.*), and on the Moss Rose it is branched (*fig. 76.*) All of these glands

Fig. 71.



Fig. 72.



Fig. 73.



Fig. 74.



Fig. 75.



Fig. 76.

are cellular, with the cells more regular than those in the substance of the leaf, and arranged in circles: a cord of vessels can generally be traced into the substance of the gland.

4. **PUBESCENCE** comprehending *Down* (*pubes*), *Hairs* (*pili*), *Bristles* (*setæ*). The structure of the first is more simple than any other part of the vegetable body, consisting of tubular cells so disposed as to form single, extended, or jointed hairs, with or without a globular point; or branched, or stellated, or uncinated or hooked hairs. The structure of *Bristles* is also cellular, but more condensed, and assuming a variety of forms, some of which, for instance the hooks in Clivers (*Galium aparine*), enable the plants to climb. Bristles are, also, sometimes the excretory ducts of

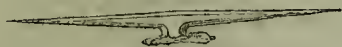
glands, as exemplified in Borage (*Be-rago*), the Nettle (*Urtica*), Loasa, &c. In *fig. 77*, which represents the sting

Fig. 77.



of the Loasa, a plant from Chili, *a* is the cellular gland where the poison is secreted, *b* the receptacle of the secreted poison, *c* the excretory tube or bristle. When the finger is wounded by the bristle, the force required to penetrate the skin presses down the dilated base of the tube upon the sponge, and forces a quantity of the fluid into the tube, whence it is ejected into the wound, and remaining there causes the pain and inflammation which succeed. The most curious of these bristles is that of Malpighia, which is a hollow, spindle-shaped body, supported horizontally on a short pedicel, (*fig. 78.*) In the stings

Fig. 78.



of the sharp ones may be traced a close resemblance to that of the bee; and serpents bite in like manner by a tooth with a channel or duct, through which the poison comes from a bag which the tooth squeezes in biting. If the bristle or sting of a nettle be examined with the microscope, its shape will be found closely to resemble the sting of the Loasa.

5. THORNS (*Spinæ*) are in general processes of the ligneous part of stems, and have nearly the same structure as branches. They are, indeed, sometimes abortive branches, as in the genus *Prunus*; sometimes the lobes of the

leaf hardened, as in the Date; sometimes hardened stipules, as in *Erythrina*.

6. PRICKLES (*Aculei*) are productions of the bark and the cutis. They consist of a mass of oblong cells, which become condensed towards the point of the prickle; and over which the common cutis of the part is thrown back.

7. PROPS (*Fulcra*). Under this term is comprehended the *tendrill*, the *claw*, the *hook*, and the *bladder*. The *Tendrill* (*Cirrhus*), is a long, cylindrical, slender, spiral organ, issuing from various parts of the plant. It consists of a cortex, which resembles that of the foot-stalk of the leaf; and of fasciculi of vessels imbedded in a cellular parenchyma. It has apertures on its surface, the same as the leaf: so that the tendrill partakes of the nature of the petiole of the leaf, and of the cuticular system of that part. The *Claw* (*ungula*) is of two kinds, the *radicular* and the *cirrhæal*. The *radicular Claw* is a small thread-like body, protruded from the stems of some flexible plants, which entering into the crevices of the bark of trees, and the cracks in rocks and walls, enables the plant to support itself perpendicularly upon such surfaces. The Ivy affords the best example of this organ. It consists of a cellular mass imbedding fasciculi of vessels, evidently proceeding from those of the alburnum; and enclosed in a cortex, the epidermis of which is covered with minute fibrils, which are the real adhering organs. The *cirrhæal Claw* is a combination of the tendrill and the claw. It is well exemplified in the Virginian Creeper (*Cissus hederacea*). As far as regards the tendrill-like portion, its structure is the same as that of the tendrill: the claw itself consists of cellular matter, which being a continuation of the parenchyma of the other part of the organ, is here checked in its extension and expands sideways, leaving the under surface almost devoid of cutis, but studded with minute warts or short fibrils (*fig. 79*), which entering into the minute pores of

Fig. 79.



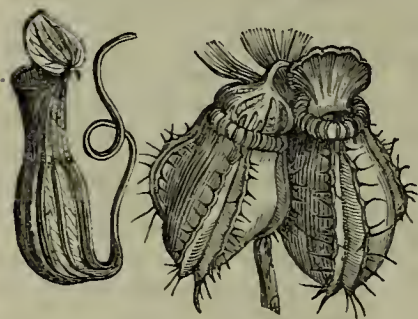
stone, bricks, &c. swell there, and maintain the claw so firmly attached, as to support the branch, and enable the plant to climb on the face of a perpendicular surface.

8. The **BLADDER** (*Ampulla*), is a small membranous bag, attached to the roots and leaves of some aquatic plants, containing a watery fluid and a small bubble of air.

9. **FOLIACEOUS APPENDAGES**, as the name implies, have the form and structure of leaves, at least this is the case in the stipule (*stipula*), and in floral leaves (*bractea*). The most remarkable of these foliar appendages are the *Ascidia* or pitchers of the *Cephalotus foliolaris* (fig. 80.), and of *Nepenthes*

Fig. 80.

Fig. 81.



(fig. 81.), which are hollow foliaceous organs, with lids that are hydrometers, opening and shutting according to the dryness or moistness of the air. Thus when the air is dry, the ring round the lip of the pitcher of *Nepenthes* contracts, and allows the lid to shut down, which is its natural tendency; but when it is moist, the ring swells with the moisture it has attracted, and forces up the lid. It is probable that the fluid contained in the pitcher is so essential to the plant, that this would be in-

jured were the fluid to evaporate wholly, which would be the case in warm, dry weather, were the lid to remain open: but, as little evaporation goes on when the atmosphere is loaded with moisture, the lid may be then opened with impunity, to admit the air into the pitcher, which may also be necessary for the health of the plant. We must admit, however, that this opinion is hypothetical. We ascertained, some time since, that the fluid found in the pitcher of *Nepenthes* is a secretion of the plant, being found in the pitcher before the lid opens, and that it is of an acid nature. This observation has been lately confirmed by Dr. Turner, by an analysis of the fluid of an unopened pitcher of *Nepenthes distillatoria*, grown in a stove of the Botanic garden of Edinburgh. The quantity of fluid procured from the pitcher was sixty-six grains. It was limpid, of a subacid taste; emitted, when boiling, an odour resembling that of roasted apples, and, when slowly evaporated, yielded minute crystals of super-oxalate of potash.

The use of these singular appendages is still unknown. Nature has been careful to prevent the fluid which they contain from being lost, when the quantity is so great that it might upset the pitcher: for this purpose, she has supplied a small hook at the back of the pitcher, close to the hinge of the lid, by which, when it is hooked upon any neighbouring part of the plant, the upright position of the pitcher is maintained. Possibly they may be both of use to the plant, and for the benefit of animals, like the hollow leaves of the Wild Pine (*Tillandsia*), which form reservoirs of clear water. That the fluid in these pitchers is a secretion of the plant itself, naturalists have now agreed.

MATHEMATICAL GEOGRAPHY.

CHAPTER I.

Universal Geography—Mathematical— Spherical figure of the Earth.

UNIVERSAL GEOGRAPHY is the science that conveys to us a knowledge of the earth, both as a distinct and independent body in the universe, and as connected with a system of heavenly bodies. The figure, structure and dimensions of the earth,—the properties and mutual relations of its parts—the features of its surface—its productions and inhabitants—and the laws which govern, or partially affect it as a heavenly body—are all included within the comprehensive term of universal geography. This definition, or rather description of the objects of geography, serves as the basis of M. Malte-Brun's elaborate work,* but it manifestly embraces a great variety of subjects, commonly classed and treated of under distinct heads of natural philosophy. To avoid, therefore, the confusion of ideas which the extensiveness of this definition may give rise to, it will be convenient to reduce its terms within the limits usually assigned to geography. And we are the rather induced to do this, because the interests of science have been promoted in no slight degree, by a judicious and well-defined arrangement of its parts, which at once excludes a great number of fanciful resemblances, and like a division of labour in mechanical employments, renders every branch more easy to be acquired, and more likely to be extended and improved.

In its proper and more confined sense, geography comprises a knowledge of the figure and dimensions of the earth, and the situation of places upon it—of the natural and political features and divisions of its surface—and of its various productions and inhabitants. These particulars may be arranged under three heads, namely, mathematical, physical, and general geography.

MATHEMATICAL GEOGRAPHY is that branch of the general science which is derived from the application of mathematical truths to the figure of the earth. Of this we shall treat first, because the other branches of geography owe to it much of their accuracy and perfection.

The figure of the earth is manifestly the first subject for inquiry;—for the principles by which we may ascertain the various truths that lie within the scope of mathematical geography, are altogether different, on the different suppositions of the earth being a flat circular plain, a cylinder, or a sphere.

A great variety of appearances, both on the surface of the earth and in the heavens, (which will be described presently) prove conclusively, that the earth is a spherical or round body. The possession of this important truth enables the geographer, by the application of the known mathematical properties of the sphere, to solve many interesting problems, the most useful of which is to determine the relative situation of places upon the earth's surface. For this and some other practical purposes, the earth is taken to be a perfect sphere; and although this supposition be not strictly true, it is sufficiently near the truth to be adopted without sensible error in the investigations into which it is commonly introduced. The nature and quantity of its deviation from a perfectly spherical shape will be for future inquiry.

At what particular period of the world the spherical figure of the earth was first discovered, cannot now be ascertained. It is natural to suppose, that the curiosity of mankind would early be directed to the shape of the earth they lived upon. But when first it engaged their attention, it fared with this as with all other parts of what is called natural philosophy. Men were led to entertain the most erroneous notions of it, by trusting too much to single appearances. Deceived by the plain-like appearance of the earth, and disregarding all other

* See Malte-Brun's Universal Geography.

circumstances indicative of its figure, they conceived it to be an extensive plain meeting the heavens on every side. Such was, for ages, the general opinion. But there were exceptions to the prevailing ignorance, which are honorable testimonies to the value of a more enlarged and extended observation of nature. The Egyptians and Chaldeans are especially entitled to this praise. The philosophers of these nations were, in all probability, led to form a correct opinion of the figure of the earth from their great practical familiarity with the appearances of the heavenly bodies. But whatever may have been the source from whence their knowledge was derived, it is manifest that they were not ignorant of its true shape, as it must have formed an element in the calculations by which they were enabled to predict eclipses of the moon. From the Egyptians and Chaldeans, who were the fathers as well of geographical as of astronomical science, the Greek philosophers, with all their most correct notions in natural philosophy, derived also their knowledge of the earth's true shape. But (as *Sir Isaac Newton* remarks) the Greeks were of themselves more addicted to the study of philology (or language) than of nature: when therefore their communications with Egypt became less frequent, the ancient philosophy gradually declined among them; and no longer retaining the just ideas they once possessed, they put forth their own visionary speculations concerning the figure of the earth. Aristotle, the most celebrated of the Greek philosophers, did not escape the error of those who allow the suggestions of fancy to occupy the place of a severe investigation into facts; and we find him alleging the earth to be of a cylindrical shape, like a common drum. The remarkable ingeniousness of the Greeks was ever impatient of the restraint which scientific inquiry in order to a successful issue imposes upon the mind; and it is to be lamented that by reason of the admiration in which their writings were held, their errors should for so long have retained possession of the human mind, and by keeping down the spirit of inquiry retarded the full establishment of what is properly called experimental philosophy.

During the greater part of that portion of the history of Europe, called the middle or dark ages, the earth was conceived to be a flat surface extending on

every side till it met the heavens. The overthrow of this popular opinion was rendered the more difficult by the Roman church admitting it into the number of articles of faith: the tenet thus became guarded with the sanction of religious belief, and by the apprehension of incurring the serious charge of heretical opinions. It is however remarkable, that the appearance of objects at sea, which are wholly inconsistent with the notion of the earth being a plain, and which lead most directly to the conclusion of its spherical shape, should not have redeemed the Venetians and Genoese, who had long been in the habit of making adventurous sea voyages, from the general ignorance. But notwithstanding the peculiar advantages enjoyed by navigators, it is evident that the best of those of the age of Columbus were not better informed of the earth's real figure. It is related as a matter of history, that the Portuguese who had arrived at the Moluccas (situated in the Pacific and to the West of America), by sailing continually in an *easterly* direction, were astonished by the appearance of Magellan's party, who reached the same point by sailing continually *west*. We may not, however, involve Columbus in this general censure; to him is properly due the glory of establishing the fact that the earth is a sphere. He was indeed eminently qualified to give a new direction to the current of opinion. In advance of the age he lived in by the extent and correctness of his information, and being at once bold in enterprise, enthusiastic in pursuit, and fertile in expedients, he possessed all the characteristics of one who is destined to overthrow a great and prevailing practical error. His persuasion that the earth was a sphere, furnished him with the happy idea of arriving at the *East Indies* by a shorter course than round the Cape of Good Hope, by sailing due *West*. He failed in his undertaking, having been misled by the error of the ancient geographers. Ptolemy's map was then in use, and the East Indies are there laid down considerably to the west of their true position. The western coast of India is by Ptolemy placed in longitude 165° east from the isle of Ferro, (one of the Canaries through which the first meridian passed,) whereas the true longitude is about 96° , thus making a difference of no less than 67° . The reasoning of Columbus was therefore right; and al-

though he was disappointed of the immediate object of his voyage, he became the discoverer of a new world, and eventually established his own opinion of the earth's spherical shape. Magellan was the first navigator who practically demonstrated the roundness of the earth; following up the opinions which Columbus among the moderns had the merit of originating, he sailed upon the project of reaching the Moluccas by a westerly passage; but being killed in the Philippine Islands by the natives, he did not complete the entire voyage round the world. Our own countryman, Sir Francis Drake, was the first person who in one voyage circumnavigated the globe; he accomplished the voyage (undertaken however solely for purposes of plunder, and marked by rapine and bloodshed) in the space of three years; and returned to England in 1560. After these voyages, the spherical figure of the earth was generally admitted by the philosophers of Europe. A spirit of investigation soon after arose, and furnished an abundance of satisfactory proofs, which, though of daily or frequent occurrence, had hitherto been unobserved or unheeded. These proofs consist in certain remarkable appearances, either of objects upon the surface of the earth itself, or of the heavenly bodies. They are of the following description:—

If a person were situated upon an open and extensive plain, he would find, that as he departed from objects, the view of which was not hindered by any unevenness in the plain, they would *gradually* disappear from their *base* upwards; in like manner, the hull of a ship proceeding out to sea becomes invisible *first*, and afterwards the masts and rigging. The *order* in which the parts of these objects successively disappear, cannot be explained by the mere supposition that the distance between the object and the spectator gradually increasing, the object becomes first indistinct, and at last invisible; because with respect to bodies whose bulk is the same from the top to the bottom, this reason is applicable to all the parts alike, and would not account for the highest part of them being always the last visible; and with respect to bodies, the bottom part of which is the largest (as in the case of a ship), it would not only be insufficient to explain the fact, but would be directly contrary

to experience, by which we are taught, that where distance alone is the cause of a body becoming first indistinct and then invisible, the larger and more bulky parts of it are seen the longest. The only supposition which can account for the *order* in which the parts of an object disappear is, that the surface of the earth is *continually and gradually* bending or curving downwards—in other words, that it is a convex surface; and the circumstance that these appearances are the same both in kind and degree all over the earth, and in whatever direction the spectator moves from the object, or the object from the spectator, proves that this convex surface is every where and in all directions precisely or very nearly the same, and, consequently, that the earth is a sphere.

The voyages of Magellan and Drake, of Anson, Cook, and Vancouver, all tend to establish the same fact; for by holding a course due west or due east, these navigators have at last arrived at the point of their departure—thus they have sailed upon a line which in one revolution returns into itself, ending where it began; and, therefore, the surface on which it was described must be a sphere, or resembling a sphere: this was further confirmed by the voyages of Captain Cook towards the South pole, from which it appeared that the course round the earth gradually diminished as it approached the pole.

The proofs derived from the appearances of heavenly bodies are even more conclusive than the foregoing. By travelling on the earth's surface from the north towards the south, a certain star in the heavens, called the pole star (which is itself almost stationary,) is observed to change its place in the heavens relatively to the spectator's horizon, and gradually *to descend*; by a movement of the spectator in the opposite direction (from south to north), the height of the same star above the horizon is observed gradually *to increase*; and in both cases this apparent change of place in the star is in proportion to the distance travelled over. This change being also observed from whatever place the movement is made (supposing it to be in a direction perpendicular to the equator or on a meridian line), cannot be otherwise accounted for than by the supposition that the earth is a sphere; and that the arc or circular space in the heavens through which the star appears

to have moved, corresponds with a similar arc traced upon the surface of the earth.

Another most convincing proof is furnished by the eclipses of the moon. These eclipses are known to be caused by the earth coming between the sun and moon, and intercepting or cutting off the supply of light from the sun which illuminates the moon's surface or disk; the dark part of the moon's disk is, therefore, nothing more than a representation of the earth's shadow at the distance of the moon. In whatever position the earth happens to be at the time of an eclipse, its shadow upon the moon's disk is always in the form of a circle or of part of a circle: the earth must therefore be a sphere, since no other than a spherical body, in every position in which it can be placed with respect to another body giving light, can cast a circular shadow upon a third body. If, however, the earth were shaped like a circular flat plain, its shadow upon the moon's disk would be circular only when either of its sides directly faced the moon: if turned edgeways towards the moon, the shadow would be in the form of a streak, and in all other positions it would be more or less elliptical, as the earth happened to be turned more or less obliquely towards the moon when she is eclipsed.

The supposition that the earth is a sphere, accounts for all the appearances we have described; while, on the other hand, the various suppositions which have from time to time been advanced, and which differ from this, are totally inconsistent with one or other of them. *Sir Isaac Newton*, in his "Principles of Natural Philosophy," has laid it down as a rule (and it is a rule as indisputably just as it is important), that "in experimental philosophy we are to look upon propositions collected by general induction from phenomena, as accurately or very nearly true, notwithstanding any contrary hypothesis may be imagined, till such time as other phenomena occur by which they may either be made more accurate or liable to exceptions;" he adds, "this rule we must follow, that the argument of induction may not be evaded by hypotheses." Applying this rule to the present subject, we may observe that the objections urged against the conclusion that the earth is spherical, however plausible, are entitled to no weight whatever, unless they are grounded upon some certain facts and natural

appearances arising from the figure of the earth, either inconsistent with the present-received theory, or which that theory is insufficient to account for.

It is hardly necessary to remark, that the expressions occasionally to be met with in the Bible with regard to the figure of the earth, and which may appear to contradict the foregoing conclusion, have been improperly and very ignorantly applied to this subject. The object of the inspired writers who used them, was not to advance a true system of natural philosophy, or to correct the popular errors of the day in matters of mere science, but to illustrate or enforce some precept or doctrine, or to record the occurrence of some remarkable event, which could not be done intelligibly, but by adopting expressions in agreement with the opinions of the age.

The re-establishment of the old and long neglected opinion of the earth's spherical shape, may justly be regarded as furnishing an epoch in the history of modern Europe. When admitted into the number of those truths which are assumed and acted upon without proof, it had an immediate and practical effect upon the common concerns of life. To traverse boundless seas was no longer matter for apprehension: the seaman was now provided with a method of discovering his relative position upon the globe, the course he had already described, and the distance and bearing of his destined port. Navigation thence assumed a bolder and more systematic character; an extensive commerce added to the wealth, and stimulated the efforts of European nations; and the more general and frequent intercourse inseparable from commerce softened the prejudices of men, and opened to them in distant climates and countries the richest and most varied stores of knowledge. We should not perhaps be justified in placing this discovery in the same rank with the other great events which happened about this æra: the invention and general introduction of the art of printing—the reformation—and the establishment of experimental philosophy, must stand alone; but it forms together with them a class of great and brilliant events, which exhibit the human mind as once more in a state of activity, and putting forth all its energies in the attainment of whatever might most conduce to the social and moral improvement of mankind.

CHAPTER II.

The Circles of the Sphere—Extent of the Visible Horizon—Method of Drawing a Meridian Line—Circles of Position—Æquator—Latitude—First Meridian—Longitude.

THE modes of precisely fixing the situation of places upon the earth are founded upon the circumstance just now proved of its spherical form, and upon the supposition which, for the purposes to which it is applied, is not a false one, that it is enclosed in a concave or hollow sphere of the heavens, of which it occupies the middle spot or centre.

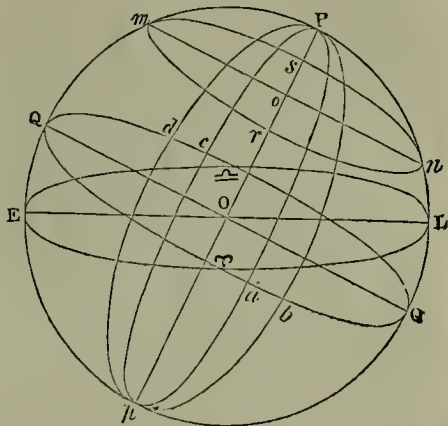
Upon the surface of the earth considered as a globe, various lines are supposed to be drawn for the purposes of geographers, and in order to determine or explain the truths of their science; and as the heavens present to us a concave sphere, having the same centre as the earth, there are also imaginary lines supposed to be traced upon the inner surface of the heavens, which exactly correspond with those traced upon the earth. By this device geography has become allied with astronomy, and has thence derived its most important improvements. We now proceed to the description of the above-mentioned lines which are supposed to divide the earth, and which are seen drawn upon the common geographical globe.

The earth has a daily motion from *west to east*, about one of its diameters (called the earth's *axis*), which causes all the heavenly bodies to *appear* to move daily round the earth in an opposite direction from *east to west*. The two extremities of this axis are called the *poles* of the earth, from a Greek word signifying a pivot; one is called the *North pole*, being that which is opposite or nearly opposite to the star in the heavens called the pole star; the other extremity of the axis is called the *South pole*; the north pole is also known by the name of the *arctic pole*, from a Greek word signifying a *bear*, the 'great bear' being the name of a constellation or collection of stars in the immediate neighbourhood of the pole star, and commonly known as Charles's wain:—the South pole has the corresponding term of the *antarctic pole*, or the pole *opposite* to the *arctic*.

Let $PEpQP$ (fig. 1) be a sphere representing the globe of the earth, O the centre, Pop the axis, P the north

and p the south pole; now suppose a plane to cut this sphere into two equal

Fig. 1.

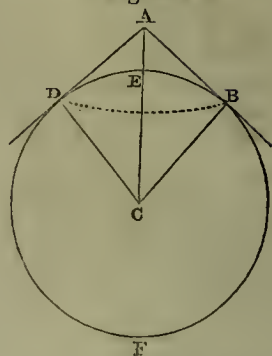


parts in a direction perpendicular to the axis, this plane will pass through the centre O , and the circle $QabQcd$, which is the boundary of the cutting plane upon the surface of the globe, will represent the *equator*, and is every where at an equal distance from both poles. This circle and all other circles, the planes of which pass through the centre of the sphere, are called *great circles*. All circles such as $PapcP$, $PbpdP$, which pass through both poles P, p , of the earth, and which have the axis of the earth Pop for a common diameter, are called *meridians*, because when the centre of the sun is over or upon that one of these circles which passes through any place, it is *mid-day* or noon at that place. The plane of every meridian cuts the plane of the equator at right angles, so that the equator divides every meridian (as for instance $PapcP$) into four equal parts; thus Pa and ap , and pc and cP are equal to one another, and are called *quadrants* or quarters of a circle. Meridians are also called circles of latitude, because upon them the latitudes of places are measured. The Ecliptic found traced upon common globes (although it is properly an imaginary circle in the concave sphere of the heavens representing the apparent path of the sun in the course of a year) is a great circle upon the globe of the earth, the plane of which is inclined at a certain angle to the plane of the equator, and is represented in the figure by the circle EOL . All circles upon the sphere which do not pass through its centre are called *small circles*; those which are parallel to the equator, as mns , are called

circles of longitude or parallels of latitude; and as all meridians cut the equator at right angles, they also cut all circles of longitude at right angles, which is evident from these latter circles being parallel to the equator. Every circle traced upon the earth is supposed to have a corresponding circle traced upon the concave or hollow spherical surface of the heavens. All circles, whether great or small, are divided into 360 equal parts called *degrees*; every degree is again divided into 60 equal parts called *minutes*, and every minute into 60 *seconds*: these various parts are distinguished by certain signs, thus 15 degrees is written 15° , 32 minutes is written $32'$, and 5 seconds $5''$; so that $15^{\circ} 32' 5''$, signifies 15 degrees together with 32 minutes and 5 seconds. The magnitude of degrees is of course different in great and small circles; the amount and variation of this difference in the circles of the globe, will be explained afterwards.

The *zenith* of any place on the earth is that point in the concave surface of the heavens which is immediately opposite to the extremity of a line drawn from that place to the centre of the earth, or in the direction of a plumb line; it is the point in the heavens directly over our heads. The *nadir* is the corresponding point in the opposite hemisphere of the heavens. Of all the meridian circles, that which passes through the zenith of a place in the heavens, or through the place itself upon the earth, is the meridian of that place. The horizon of a place is the boundary of view at that place: with respect to the earth it is called the visible, sensible, or apparent horizon; with respect to the heavens it is called the rational, true, or astronomical horizon. The visible horizon is most accurately observed upon the sea where it is distinct and unbroken, and is, therefore, sometimes called the horizon of the sea. The extent of the visible horizon may easily be found if the height of the spectator's eye above the surface of the earth be known, and also the length of the earth's radius or semi-diameter. For if (fig. 2.) B E D F be a great circle, C the centre of the earth, A E the height of the eye, E C the semi-diameter of the earth, and A B be drawn from A, just touching the earth's surface at B, E B will be the extent in one direction of the visible horizon. If B and C be joined, B C will be perpendicular to A B. The

Fig. 2.



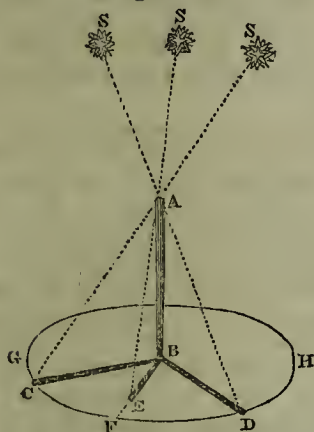
length of A E and E C or A C and also of B C, which is the semi-diameter, being known, the angle A C B may be found by a very simple mathematical process; and this angle being measured by the arc E B, the required distance is found. A B, the direct distance of the horizon at B from the spectator's eye at A, may also be found in a somewhat similar manner:—if A E be equal to 5 feet, and E C, the semi-diameter of the earth, be taken at 29,949,655 feet, the angle at C, or the arc B E, will be found to be equal to $2'$ or 12,188 feet, which is nearly equal to 2 miles and 532 yards; D B is of course equal to twice B E, as the spectator sees as far one way as another, therefore D B is equal to 4 miles 1064 yards. This, however, is not quite true in practice, as by the refracting power of air and vapour, the apparent horizon is a little more extensive. The rational horizon is in every part of it 90° , or a quadrant distant from the zenith. When a heavenly body first appears above the horizon of a place, it is said to rise, and to set when it disappears or sinks below the horizon. When a heavenly body is upon the meridian of any place, it has obtained its greatest height or altitude above the plane of the horizon of that place.

The north point of the horizon is that which is nearest to the north pole of the heavens or the pole star, the point 180° distant from it is the south. The meridian line of a place passes through the north and south points. The east point is 90° distant from the north or south in that portion of the heavens where the sun, stars, &c. appear to rise; the west is 180° distant from the east point. Thus all the cardinal or principal points of the compass are determined.

By means of the observed altitudes of heavenly bodies, when at their highest or on the meridian of a place, many

geographical problems are solved; it is, therefore, of great importance to ascertain the direction of the meridian line at the place of the observer. The operation in its more scientific and correct shape is one of very considerable nicety; but the following method will determine it, if much accuracy be not required. On the 15th of June, or the 24th of December, plant a stick *AB* in a position perpendicular to the horizon (*fig. 3.*) at an hour or two before the

Fig. 3.



sun has arrived at its greatest altitude in the heavens, that is, be at ten or eleven o'clock in the morning; mark accurately the extremity *C* of the shadow *BC* cast by the stick; then from the base *B* of the stick as a centre, and with the length of the shadow *BC* as a radius, trace a circle *GH* upon the ground; as the sun gradually arrives at its greatest altitude, the shadow of the stick will become gradually shorter, and will fall within the circumference of the circle which has been traced. The shadow will be at its shortest *BE*, when the sun is at its greatest altitude, or when it is on the meridian of the place which is the moment of noon; after this the sun will gradually decline, the shadow of the stick will become longer and longer, until at last it again reaches to the circumference of the circle in the point *D*, at which time in the afternoon the sun is at the same height in the heavens as it was when the shadow of the stick was of the same length *BC* before noon. Now it so happens, that, on the above-mentioned days, the altitude of the sun above the horizon, at one hour or two hours before noon, is equal to its altitude at the same time after noon; and as the sun has in these equal times before and after noon, described equal

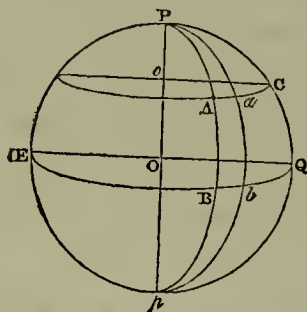
spaces in the heavens (supposing those spaces to be measured from the meridian), the middle point of the whole space described by the sun in the sum of those times will be that point in the heavens which the sun occupies when it is noon; at this time the sun is on the meridian. Hence, if the arc *CD* of the traced circle be divided into two equal parts *CF* and *FD*, and the point *F* of division and the base of the stick be joined, the line *BF*, joining these two points, and which will be the direction of the shadow of the stick at noon, will be the meridian line. The longest and most accurate meridian line in the world, is that drawn by Cassini (a celebrated astronomer and mathematician) upon the pavement of the church of St. Petronis, at Bologna, in Italy: it is 120 feet in length.

One of the principal objects in mathematical geography is to ascertain the position of any particular spot upon the earth's surface. This term *position* is strictly a relative one—applied to a body, it has no meaning unless there be some other body or mark, which is fixed, and to which the first body may be referred. If, in the midst of infinite space, there existed but a single body, it could hardly be said to have position, or at any rate the meaning of the term as applied to such a body would pass our comprehension. This may be illustrated by what is said in some books on mechanics, that motion could not exist if there were but a single body in the universe; by which is meant that in such a condition of things motion could be neither measured nor perceived: it is not intended by such expressions to assert that motion cannot exist independently of other bodies, because the existence of a foreign body cannot really affect the state or condition of motion in any moving body; it only enables us to ascertain the fact of motion, and its measure. In the idea of position, therefore, there is contained a reference to something which is fixed and which is independent of the body, the position of which is required. The distance of any body from this something which is fixed being known, and also the direction given in which that distance is to be measured, its position may be determined.

In order to ascertain the situation of any spot upon the surface of the globe, it is sufficient to fix upon two great

circles, the planes of which are perpendicular to each other, and from each of which the nearest distance of the spot is to be measured; these two great circles are called circles of position. Thus if (see *fig. 4*) the position of the point A upon the surface of the sphere or

Fig. 4.



globe PCEP be required—it may be determined if we have given in position the great circle CEBQ, and the great circle PaBp, the planes of which are perpendicular to each other. For we need only make a great circle PABp perpendicular to the circle CEBQ pass through A, and then a small circle pass through A parallel to CEBQ, and the distances of their intersection from the given great circles, viz. the arc AB being the distance from CEBQ, and the arc Aa, or the corresponding arc Bb, being the distance from PaBp, will determine the exact position of the point A.—In applying this to the practical purposes and wants of geography, it is evident that the first object is to fix the position of the two great circles CEBQ and PaBp, and then to devise some mode for ascertaining the distances AB, Aa from each of them.

The astronomers and geographers of all countries have concurred in fixing upon the *equator* or *equinoctial line* (as it is sometimes called) for the position of the circle CEBQ. The equator has been already defined as a great circle dividing the globe into two equal parts or hemispheres, and the plane of it as perpendicular to the axis of the earth. The distance AB measured upon the meridian of A, which is a great circle perpendicular to the equator, is called the *latitude* of A. The latitude of a place is north or south latitude, as it is situated towards the north or south of the equator. It is very evident that astronomers were led to fix upon the equator for one of the great circles of position, by the circumstance of the ap-

parent daily motion of heavenly bodies, being performed either in a circle in the heavens corresponding with the equator itself, or in circles which are parallel to it. But as there was nothing in the apparent courses of heavenly bodies, or in any particular spot upon the earth to regulate the choice of astronomers in fixing upon a first meridian or the other great circle of position perpendicular to the equator, and which is represented in the preceding figure by the circle PaBp, the consequence has been, that astronomers and geographers of different ages and countries have assumed different circles for their first meridian, from which they have measured the arc Aa or Bb.

The ancient geographers took for their first meridian the meridian of the Fortunate Isles, a line passing, as they conceived, through the western extremity of the habitable earth. Many of the moderns have employed the same meridian, or rather that of the island of Ferro, one of the most westerly of the Canaries. In general, however, nations adopt as their first meridian the meridian of their own metropolis, or of their principal observatory, as the English do that either of London or Greenwich, the French that of Paris. The angular distance on the arc Aa or Bb of any place from the first meridian is called its *longitude*, and is either east or west longitude as the place is to the east or west of the first meridian. The English map-makers frequently adopt the meridian of London instead of that of Greenwich for the first meridian, but as London (taking St. Paul's as the point referred to) is 5' 47" west of Greenwich, longitudes given from London may be easily reduced to longitudes reckoned from Greenwich, by adding to them 5' 47" if they are west longitudes, and subtracting the same quantity if they are east longitudes.

CHAPTER III.

General Description of the Method of finding the Latitude of a Place.

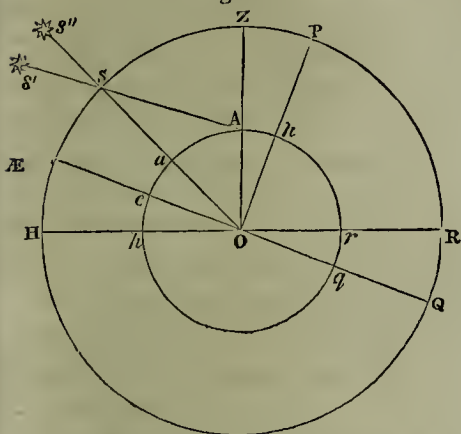
HAVING fixed upon the two circles of position by a reference to which the position of a place is to be determined, it will now be necessary to explain how distances from each of these circles (being the latitudes and longitudes of places) may be ascertained. This depends entirely upon the supposition that

the earth is a spherical body situated in the middle or centre of the concave or hollow sphere of the heavens, and that every circle traced upon the globe of the earth has a corresponding circle in the heavens.

We shall begin with the latitude of places.

Let A be any place upon the earth's surface, and suppose in the annexed figure (fig. 5) that $Aprqhe$ is the me-

Fig. 5.



ridian of A passing through p , the pole of the earth, and at right angles to the equator (eq), the plane of the paper is the plane of the meridian, O the centre of the earth, PO its semi-diameter, to which (eq), the equator, is at right angles, HR the rational horizon of A. Then Ae , the arc or angular distance of A from the equator measured upon the meridian of A, is the latitude of A. But ep , or the distance of the pole from the equator, is 90° , or a quadrant, and Ar the distance of A from the point r , where the rational horizon meets the surface of the earth, is also 90° , or a quadrant. Hence ep is equal to Ar ; if therefore Ap , which is common to both ep and Ar , be taken away from each, the remaining quantities Ae and pr will be equal; and as Ae is the latitude of A, it follows that (pr) or the height of the pole above the horizon is equal to the latitude of the place.

Again, Ap is the distance of the pole from A: and as Ae is the latitude of A, and pe is 90° , Ap is the difference between 90° and the latitude, so that if Ap be known, Ae , or the latitude, is found, by subtracting Ap from 90° . Ap is called the complement of the latitude, or the co-latitude.

Again, Ah is 90° , and, therefore, Ae being the latitude, he is the co-

latitude,— he , being the height of the equator above the horizon; so that if he be known, the latitude is found by subtracting he from 90° .

It appears, then, that if we can find any one of the above four arcs, viz., Ae , pr , Ap , he , the latitude of A will be known: and the mode of determining these arcs, is by measuring similar arcs of corresponding circles in the heavens. Let $ZPRQH\hat{A}E$ be the circle in the heavens which corresponds with the meridian circle passing through A, and Z, P, R, Q, H, $\hat{A}$, points in the heavens corresponding with A, p , r , q , h , e . The attention of the geographer is then transferred from the consideration of the several arcs Ae , pr , Ap , he , to the corresponding arcs in the circle in the heavens, $Z\hat{A}$, PR , ZP , $H\hat{A}$: for if any of these be determined in their number of degrees and parts of degrees, the latitude is found directly. Thus it is, that the geographer depends so much upon the science of astronomy for the solution of the most important geographical problems. Persons who are in the slightest degree acquainted with geometry, or with the most simple properties of the circle, will not object to the above-mentioned mode of determining the latitude of places on the earth by means of corresponding arcs in the heavens, that these corresponding arcs are of different magnitudes; for in computing the latitude, we do not so much want the actual admeasurement and linear quantity of the arc of the meridian intercepted between the given place and the equator, as the number of degrees and parts of a degree which it contains, or, in other words, the proportion which this intercepted arc bears to the whole circumference of the meridian circle. And as arcs are the measures of angles, the arcs, $Z\hat{A}$ and Ae , are both measures of the same angle at o ; and, therefore, although they are unequal in magnitude, yet they mutually bear the same proportion to the circumference of the circles of which they are parts; that is, $Z\hat{A}$ contains the same number of degrees as Ae : and as the latitude of a place is always expressed in degrees and parts of degrees, the number of degrees contained in the arc in the heavens, $Z\hat{A}$, which corresponds with the arc of the meridian Ae , will be the latitude of A. If, after having ascertained the latitude in this manner,

that is, in degrees and parts of degrees, the actual linear magnitude contained in the latitude, or the geographical distance between A and the equator measured upon the meridian, be required, it may be obtained thus. Let an observer at A travel upon the same meridian in a direction due north or due south, (*i. e.* from or towards the equator,) until the pole star has, with respect to the observer's horizon, been raised or sunk one degree (which may be known from observation): then as the star is itself stationary, this gain or loss of one degree in its station with respect to the horizon, has been caused by the observer having travelled exactly one degree, measured upon a meridian of the earth, nearer or farther from the north pole. If this space be actually measured, the result, expressed in linear measure, will give the magnitude of a degree of latitude in geographical miles and parts of a mile; the quantity thus found, being multiplied into the number of degrees and parts of a degree, will give the actual linear distance between A and the equator. The process thus conducted is on the supposition that the earth is perfectly spherical. A degree of latitude measured in this manner contains about sixty-nine miles.

How the spaces or arcs $Z\text{Æ}$, $P R$, $Z P$, $H\text{Æ}$ in the heavens are to be measured by a spectator at the spot A on the surface of the earth, is now to be explained. This is done by means of observations made by the spectator at A, upon some heavenly body, with an instrument adapted for the purpose of measuring circular arcs: by these observations, which are made when the heavenly body is either upon the meridian of the place or not, the angular distance of the body from the zenith or from the horizon is ascertained. Thus if s be the sun (see *fig. 5.*) on the meridian, its angular distance $s Z$ from the zenith, (called its zenith distance,) or its angular distance $s H$ from the horizon, (called its altitude,) is measured, and ascertained in degrees and parts of degrees.

As, however, A is the place at which these observations are made, the angle $Z A s$ is all that can be determined from observation; but this angle is not the measure of the arc $Z s$, because A is not the centre of the sphere of the heavens; but the angle $Z O s$ is the proper measure of this arc, since, by the supposition, the

meridian circle and the corresponding one in the heavens have the same centre, O; and it is a well known truth in geometry, that the angle $Z A s$ is greater than the angle $Z O s$ by the angle $A s O$. This conclusion, expressed in common language, may therefore be stated thus: that a spectator at A, looking upon a heavenly body at s , will see it lower down in the heavens, namely, at s' , or farther removed from the zenith point Z, than a spectator situated at the centre of the earth, who would, at the same instant of time, see the same body at s'' ; the difference of the *apparent* places which the body, s , will thus occupy in the heavens, as seen from the surface of the earth, and as seen from the centre, is the angle $s' s s''$, which is equal to the angle $A s O$. This angle is formed by two lines drawn from the extremities of the earth's radius, or, in geometrical language, is the angle subtended by the earth's radius, at the distance of the body s . This angle is called the *parallax** of a heavenly body, and increases the zenith distance of s . It is obvious that parallax produces a contrary effect upon $H s$, the altitude of s , and that as the zenith distance is *increased* by the angle $A s O$, so the horizontal distance or altitude is *diminished* by the same angle. *The general effect, therefore, of parallax is to depress a heavenly body.* If, however, the distance of the body upon which an observation is made, be so great, that it would be seen in exactly the same position in the heavens by a spectator at the surface of the earth, and one at the centre, it is evident that the angle $s' s s''$ or $A s O$ (the parallax) would be so small as to escape observation, and would, to our senses, vanish. This is the case with the fixed stars; but with respect to the sun and moon and planets, whose distances are not so great, the parallax has an observable effect upon their apparent positions, as they are seen from different parts of the earth's surface, or from the earth's surface and its centre. And this circumstance raises a necessity for correcting the *observed* distances of these heavenly bodies from the zenith or horizon of a place, in order to arrive at the *true* distance, as they would be seen from the earth's centre, and that the respec-

* From a Greek word, and thus applied, signifies simply a *change* of place.

P the north pole, and s the circumpolar star on which the observations are to be made. The little semicircle drawn through s and s' , parallel to the equator, will represent the apparent path of the star in its motion caused by half a daily revolution of the earth. It is evident from a mere inspection of *fig. 6*, that the star's greatest and least altitudes above the horizon will be when the star is on the meridian; its greatest when it is above, its least when below the pole P. Let s be its position in the first case, and s' in the other; then $R s$ is the star's greatest altitude, $R s'$ its least altitude. By means of either of the instruments called an astronomical quadrant, or an astronomical circle, $R s$ and $R s'$ may be observed and measured, and the number of degrees and parts of degrees contained in it be ascertained. Then as the half-circle $s' s$, which the star has described in its apparent motion from s' to s , is parallel to the equator, (for the motion of the earth, which is the cause of this apparent motion of the star, is perpendicular to the axis of the earth, so that the path of the star is also perpendicular to the axis, and therefore parallel with the equator;) and as the equator is every where at the same distance, *viz.*, 90° from the pole P, the half-circle $s' s$ is also every where at the same distance from P; therefore $P s'$ is equal to $P s$.

On the Methods of Determining the Latitude.

1st. By the altitudes of those stars (called circumpolar stars), which never go below the horizon of the place the latitude of which is required.

2ndly. By the greatest and least altitudes of the sun above the horizon of the place in the course of the year.

3rdly. By the observed altitude or zenith distance of a star or other heavenly body when on the meridian.

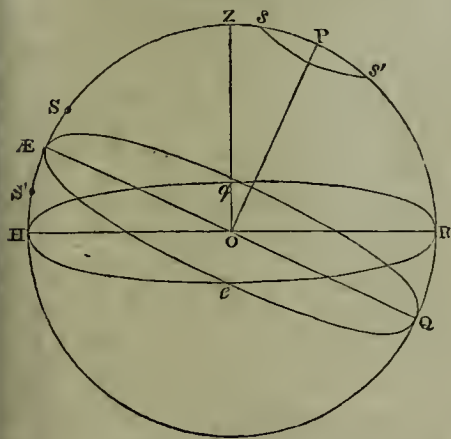
4thly. By the zenith distances of stars, which pass the meridian near to the zenith of the place.

5thly. By various altitudes of a star, observed when it is near to the meridian, and then reduced to the meridian by computation.

1st Method.—By the altitudes of circumpolar stars.

Suppose (*fig. 6.*) that $Z P R Q H$ $\mathcal{A}$, is that imaginary circle in the con-

Fig. 6.



ave surface of the heavens which corresponds with the meridian of the place the latitude of which we want to find. Let O be the centre of the earth, HR the rational horizon, ÆQ the circle of the equator extended to the heavens,

Now R_s , which is known from observation, is equal to $PR + Ps$; and R_s' , which is also known from observation, is equal to $PR - Ps'$, or $PR - Ps$. Adding these two quantities, R_s and R_s' together, we have $R_s + R_s'$, equal to $2 PR$; therefore PR , or *the height of the pole above the horizon*, (which has already been proved to be equal to the latitude of the place $Z\hat{A}E$,) is equal to $\frac{1}{2}$ of $R_s + R_s'$, or *one half the sum of the greatest and least altitudes of a circumpolar star*, which altitudes being known from observation, the latitude of the place is found. This mode of finding the latitude does not require any correction to be applied to the observed altitudes on account of parallax, as the body observed is a fixed star; but a correction of these altitudes is required, in consequence of the refracting power of the air and vapours which surround the earth and have effect upon the apparent places of heavenly bodies, contrary to the effect of parallax,—parallax

making bodies appear lower in the heavens; whereas, a ray of light passing through the atmosphere becomes refracted and bent downwards, and the body from which the ray proceeds, appears above its true place in the heavens. The space through which a body is raised by refraction (and which is different for different altitudes), is given in tables computed for various altitudes; this correction must, of course, be *subtracted* from the *apparent observed* altitudes.

2dly. By the greatest and least altitudes of the sun above the horizon in the course of a year.

The path in which the sun's apparent yearly motion in the heavens takes place (called the ecliptic) is, at one point of it, about $23^{\circ} 28'$ on the north side of the equator; and, at the exactly opposite point, it is the same number of degrees and minutes on the south side of the equator. These two points of the ecliptic are the farthest off from the equator, and are exactly 90° distant from the two points where the ecliptic and equator cut each other, which are called the equinoctial points. The sun is in the former point on or about the 24th of June, and in the latter on or about the 24th of December. To all persons, therefore, living between the north pole and latitude $23^{\circ} 28'$, it will, on the 24th day of June, when it comes on the meridian, be the highest above the horizon, or have its greatest altitude, compared with its altitude on every other day in the year; and, in like manner, it will, on the 24th of December, have its least meridional altitude. Let S (fig. 6.) be its position in the former, and S' in the latter, of these two cases. Then, as $\mathcal{A}$ is the point in the equator from which S and S' are both distant $23^{\circ} 28'$, $\mathcal{A}S$ and $\mathcal{A}S'$ are equal. The altitudes of the sun's centre in both positions are to be observed with an instrument, which observation, when corrected for parallax and refraction, will give HS and HS' , the greatest and least meridional altitudes of the sun in the course of the year. Now, $H\mathcal{A} = HS - \mathcal{A}S$, and $H\mathcal{A}$ is also $= HS' + \mathcal{A}S'$ or $\mathcal{A}S$, and therefore $2 H\mathcal{A} = HS + HS'$; and $H\mathcal{A}$, the height of the equator above the horizon, or the *co-latitude* of the place, is equal to $\frac{1}{2}$ the sum of the greatest and least meridional altitudes of the sun in the course of the year. As, however, it seldom happens in practice that the sun, when it comes upon the

meridian of the observer, is exactly at that point of its path where it is farthest from the equator, but has either already passed that point, or has not yet quite reached it, certain corrections upon the observed altitudes become necessary, in order to allow for this circumstance.

3dly. By the observed altitude, or the observed zenith distance of a star or other heavenly body, when on the meridian.

This method of finding the latitude is that which is generally employed for common geographical purposes. It is the most simple in practice, as depending only upon one observation, and is also, on this account, the most immediate in its result. It is also adapted for nautical purposes, the only difference between the modes of conducting the operation on land and at sea being in the instruments employed for making the observations, and also that, at sea, the heavenly body selected for observation is either the sun or moon, because, from the motion of the vessel, it is difficult to obtain a correct observation of the meridian altitude of any body having so small an apparent magnitude as a star. A few remarks will be made in a subsequent page, explanatory of some of the peculiarities of the modes of finding the latitude at sea: we shall, therefore, in the present instance, confine ourselves to the supposition, that the observer who is about to adopt this method of ascertaining his latitude, is on land.

Suppose (fig. 6.) S or S' to be the star or other heavenly body which is selected, S being a heavenly body above the equator, S' being a heavenly body below it; the observation is to be made when the body is on the meridian. Let ZSH represent a portion of the meridian in the heavens, and $\mathcal{A}eQq$ represent the equator: SH or $S'H$ is then ascertained from observation, if the altitude be taken; or SZ or $S'Z$, if the zenith distance be taken; which it is more usual to take, as, from the inequalities of the earth's surface, it is difficult to obtain on land a true horizontal boundary. These observations must be corrected for parallax and refraction, if the body be either the sun or moon; and for refraction only, if it be a fixed star. Now, the object being to ascertain either $\mathcal{A}H$, the height of the equator above the horizon (which has been already shown to be equal to the co-latitude), or $\mathcal{A}Z$, the zenith distance of the equator,

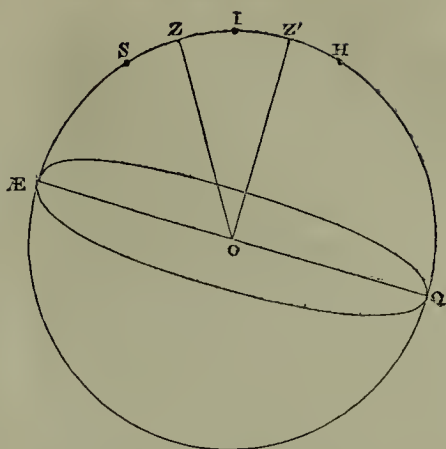
which is the latitude,) it is evident that the distance of the observed heavenly body from the equator—that is, $S\text{ } \mathcal{A}E$ or $S'\text{ } \mathcal{A}E$, be known, the *co-latitude* will be found by subtracting $S\text{ } \mathcal{A}E$, or adding $S'\text{ } \mathcal{A}E$ to the observed *altitude*; and the *latitude* will be found by adding $S\text{ } \mathcal{A}E$ in the one case, and subtracting $S'\text{ } \mathcal{A}E$ in the other, according as the body observed is above or below the equator. Now, $S\text{ } \mathcal{A}E$ or $S'\text{ } \mathcal{A}E$, which is the distance of a heavenly body from the equator, measured upon a meridian in the heavens, is called its *declination*, and is either *north* or *south* declination, according as the body is nearer and farther off the *north* pole than the equator. This declination is either computed by the observer by certain astronomical calculations, or it is taken out of astronomical tables. The Nautical Almanack gives the declination of the sun and moon for every day in the year. From the foregoing explanation of this method, the following general rule is derived for finding the latitude by means of meridian altitudes, or zenith distances of heavenly bodies. If the heavenly body have a north declination, add the declination to its observed zenith distance (corrected), or subtract it from its observed altitude (corrected), and the latitude in the first case, and the *co-latitude* in the other, will be obtained. If the body have a south declination, the same result will be obtained by subtracting the declination from the zenith distance, and adding it to the altitude.

4th. By the zenith distances of stars which pass the meridian near to the observer's zenith.

When this method is adopted, the observations are generally made at two places having different latitudes; and the latitude of one of the places is supposed to be previously known. It is immaterial whether both places are or not situated upon the same meridian; the star must be one which passes near the zenith of *both* places. The observations are generally made at both places on the same day; if they happen to be made on different days, various corrections become requisite, which it is as well, if possible, to avoid.

The instrument employed on this occasion is one called a zenith sector, by which small zenith distances can be measured with great exactness. Let Z , Z' , (fig. 7.) be the zeniths of any two places, $\mathcal{A}Q$ the equator; and suppose that the latitude of the place whose

Fig. 7.



zenith is Z (that is, $Z \text{ } \mathcal{A}$), is known, the object is to find the latitude of the place of which Z' is the zenith (that is, $Z' \text{ } \mathcal{A}$). The zenith distances of the star S , when it comes on the meridians of both places, must be observed. These observations will give us ZS and $Z'S$. Then if S is to the south of both zeniths, as in the figure, or to the north of both, $Z'S - ZS$, or the difference between the observed zenith distances, will give ZZ' ; if S be to the north of one zenith, and to the south of the other, then $ZS + Z'S$, or the sum of the zenith distances, will give ZZ' . Now ZZ' is the difference of the latitudes of the two places, as is evident by an inspection of the figure; and therefore $Z \text{ } \mathcal{A}$ being known, we get the latitude $Z' \text{ } \mathcal{A} = Z \text{ } \mathcal{A} + ZZ'$. This method was used in the trigonometrical survey of England, and gives the latitude with great accuracy.

5th. The remaining method is by making several successive observations upon the same star at several and successive altitudes above the horizon, when it is near the observer's meridian. The various altitudes thus obtained are made the basis of a computation by which *the star's actual meridional altitude* is obtained. This is called reducing the observed altitudes to the meridian. It is a process too intricate to be introduced in this place. The star's meridional altitude is thus obtained with great exactness. The latitude is then very easily ascertained by the application of the third method. This mode of computing the latitude, by which it may be obtained to within the fraction of a second, is that which was employed by the French astronomers in their last

operation of measuring an arc of the meridian.

At sea none of the preceding methods, except the third, are ever employed; *the first and fourth* are founded upon observations made with instruments requiring some nice adjustments by means of the plumb line and the spirit level, in order that the instrument may be placed exactly in the plane of the meridian and in a horizontal position—these adjustments cannot be made at sea, owing to the unsteady motion of the vessel: the fourth method is moreover not applicable to all places; the *second* method would clearly be useless, since at sea an immediate result is required; and the *fifth* is too complex in its calculations to be fitted for nautical purposes. The instrument used at sea is Hadley's sextant, by which any angles whatever may be measured, and it does not require any previous adjustments, being held in the hand of the observer. The horizon being well defined at sea, the *altitudes* of heavenly bodies are taken. The observations are taken when the sun or other body is *near* the meridian, and are continued until it is found that its altitude has attained its greatest quantity and begins to decrease: at its greatest altitude the body is on the meridian of the observer at S (*fig. 6.*); the complement of the latitude is, therefore, obtained, as in the third method, by adding or subtracting the distance of the observed body from the equator, according as it is below or above it, or has a south or north declination. The sun or moon is commonly the object observed, and *the Nautical Almanack gives the declination of these bodies for every day in the year.* The corrections for parallax and refraction must be made upon the observed altitudes. Besides these corrections, another is rendered necessary, in consequence of the observer being elevated above the surface of the sea. This elevation causes a correspondent depression or sinking of the horizon, and gives a greater apparent altitude to the observed body than it really has. This correction is called the dip.

But as it frequently happens that, at the time when the sun or moon is on the meridian, clouds prevent the observing of its *meridional* altitude, the latitude may then be obtained by observing two altitudes *out* of the meridian at different times, and noting the interval of time which elapses between the times of observation. ZP (*fig. 6.*), or the

co-latitude, is then computed by the resolution of three spherical triangles, a mere mathematical process, which we need not stop to investigate.

CHAPTER V.

Longitude—Mode of Measuring Time—Sidereal Time—Apparent Solar Time—Mean Solar Time—Equation of Time.

HAVING by one of the foregoing methods ascertained the parallel of latitude in which any particular place is situated, the next inquiry is directed to the finding of the longitude, or the position which a place occupies in the parallel with respect to what is called the first meridian. In this country the meridian of the observatory at Greenwich is generally taken for the first meridian. Various are the methods which have been proposed for finding the longitudes of places; in every point of view the subject is one of very considerable interest, not only on account of its great importance in commerce and science, but also because the attempts which have for so many years been made, in order to determine the longitude with the same accuracy with which the latitude of places is found, have hitherto been unsuccessful. Since the time of Queen Anne it has been regarded as an object of great national importance; and a board, called the Board of Longitude, consisting of various official and scientific persons, was then established for the purpose of encouraging and directing attempts to determine it.

All the methods for finding the longitudes depend upon the manner in which time is measured; and in order to attain a clear notion of them, it will be proper to explain at some length how a measure of time is obtained.

Properly considered, time is, in itself, without parts, and indivisible; the flow or lapse of time is, however, capable of being measured by means of events happening in time, and which, when compared one with another, are of different continuance, taking up more or less time in their completion. Time and space are in one respect similar; space is in its nature indivisible, it does not contain within itself any marks or circumstances of division; but by means of bodies which are situated within it, we are able to consider space as though it were divided into parts. What bodies

are, in this respect, to space, that precisely are events to time; they afford us the means of measurement. This is done by the comparison of those events one with another in respect of their duration; but in order to do this with accuracy, it is necessary to possess some *standard event* which always takes up exactly the same time, and to which we may refer as affording, by comparison with it, a measure of the duration of all other events: without this we should be at a loss to ascertain exactly how much time is taken up by any other event, and be left to the uncertainty of only probable conjecture. In this particular there is also a similarity between time and space; for, in measuring space, the object has been, even in remote periods of history, to fix upon a certain standard. Thus our king Henry the First commanded that the standard of measure of length should be of the exact length of his own arm, which is our present yard measure. But with him perished the standard by which the measure called a yard might afterwards be compared, corrected, and ascertained afresh. It is clear that something which was liable neither to decay nor variation was requisite to form a proper standard of measure; and accordingly by the recent Act of Parliament for weights and measures, and which proceeds upon more scientific principles, such a standard has been established in the length of a pendulum beating seconds of mean time in the latitude of London. On observing the various occurrences or events in nature, with a view to fix upon some one event, as a standard for the measure of time, it was discovered that the motion of the earth round its axis possessed all the qualifications requisite for such a purpose. This event is invariably of exactly the same continuance, and it is the only one in nature with which we are acquainted, that is so. The time spent in one revolution of the earth round its axis forms, therefore, an exact and perfect standard measure, by reference to which the time taken up by all other events may be ascertained. The beginning and the end of the revolution, and consequently the duration of it, is determined by means of the fixed stars: these stars have no motion of their own; so that their apparent daily motion is caused by the daily motion of the earth on its axis. Hence, if a fixed star be upon the meridian of a place, this motion of the earth, which is in a direc-

tion from *West to East*, gives to the star an *apparent* motion towards the *West*; and when the star next appears upon the same meridian, having moved through 360° , an entire revolution of the earth has been accomplished. The time spent in performing this revolution is the standard measure of time, and it is called a *sidereal or star day*, because it is by the appearance and re-appearance of the same star in the same place in the heavens that the completion of the revolution is ascertained. This standard being once established, it may be divided into smaller portions of time at pleasure. Portions of time measured by a reference to this standard are called *sidereal time*. Astronomical clocks are made to show sidereal time.

But it was requisite, for the sake of convenience, to obtain some other standard of measure of time, having reference to the sun, by which the common affairs of life are regulated. Now the same motion of the earth about its axis, which has already been noticed with respect to the fixed stars, gives to the sun also an apparent daily motion from the east towards the west. When the sun is upon the meridian of a place it is *apparent noon* at that place, or, in popular language, the hour of twelve in the day. After this hour, the sun, leaving the meridian, appears gradually to travel towards the west. This westerly motion continues below the horizon until it has brought the sun to a point where it rises again, and proceeding in its daily course, again reaches the same meridian on which it appeared at the hour of apparent noon on the former day. The time which has passed between these two successive appearances of the sun on the meridian of any place is called a solar day. A solar day is longer than a sidereal day; for if upon any day the sun and a fixed star be observed to be upon the meridian of a place together, the star will, on the following day, return to the meridian a few minutes before the sun. This difference in the times of the sun and a fixed star leaving and returning to a particular meridian, is caused by the sun's apparent yearly motion in the ecliptic, which being in a direction from *west to east*, and opposite to that daily motion which brings it to the meridian, makes the star, which has only the daily motion, from *east to west*, to appear on with the meridian before the sun. The daily *average* amount of this yearly motion of the sun in an *easterly*

direction *away from a meridian*, is $59' 8''$ (nearly one degree)

We have called this $59' 8''$ the daily *average* amount of the sun's yearly motion, because, during some parts of the year, it is more than $59' 8''$, and at others less. Hence it follows, that the intervals of time, which in the course of a year elapse between the sun's successively leaving and returning to the same meridian, are of different lengths. An *apparent* solar day, therefore, or the time between two actual successive passages of the sun over the same meridian, could not be adopted as a standard measure of time, because it is a varying, fluctuating quantity; and it is essential to a standard measure of time, that it should be a fixed quantity. This gives rise to an artificial solar day, called a *mean* solar day; the length of which is the *mean* or *average* length of all the various *apparent* solar days in the course of a year; and the difference in length between a mean solar day and the apparent solar day for the time being, is called the *equation of time*.

When time is reckoned with reference to the apparent solar day, it is called *apparent* time; when with reference to the mean solar day, it is called *mean time*. A common sun-dial shows the hour of apparent time. Time-keepers or chronometers, common watches and clocks, are made to show the hour of mean time. Both the apparent solar day, and the mean solar day, are divided into 24 hours; and are, for astronomical and scientific purposes, reckoned from noon to noon. The mean day is always of the same length, and although it is longer than the sidereal day, yet the quantity by which it is greater (*viz.* the time required for the earth by its motion on its axis to move through $59' 8''$ of space) is always the same.

Hence, the uniformity and equal length of mean days, and of seconds of mean time, really depend upon, and must at last be referred to the uniform and equal motion of the earth upon its axis, which consequently is the standard, by reference to which, the measure of time afforded by the pendulum beating seconds of mean time is ascertained, and may be corrected. It is not uninteresting to observe, that to the equable and invariable motion of the earth about its axis, we are indebted, not only for a standard measure of time, but also for all our standard measures of length, capacity, and weight; since, by the recent Act of

Parliament, before referred to, all of them are referred to the length of a pendulum beating seconds of mean time in the latitude of London.

At four times in the year, and only four,—that is, on or about the 15th day of April, and the 1st of September; and on or about the 15th of June, and the 24th of December,—mean time and apparent time agree; or, which is the same thing, on these four days the sun is actually upon the meridian of some particular place, and the shadow of the style of a dial at that place is upon the hour of twelve, at the very moment that a correct time-keeper, or watch measuring mean time, and adjusted for this particular place, shows the hour of 12. Throughout the rest of the year, apparent time and mean time are different. The exact amount of this difference is easily calculated for every day: it is called the *equation of time*; because, by either adding it to, or subtracting it from, the time of the apparent solar day, the result will be, the time of the mean solar day. The equation of time is given for every day in the year in the Nautical Almanack, with directions, showing whether it is to be added to or subtracted from the *apparent* time, in order to get at the mean time.

CHAPTER VI.

Various Methods of Finding the Longitude.

IN the application of the above-mentioned principles for reckoning the time of the day, consists the simplest method of finding the longitude of a place, or its situation in a given parallel of latitude with respect to the first meridian, the meridian of Greenwich.

As in the 24 hours into which an *apparent* solar day is divided, the sun returns to a meridian which it has left, it may be said to describe, in that time, 360 degrees of longitude; which, dividing the whole 360° by 24, and supposing the motion to be uniform, is at the rate of 15° of longitude for every hour of apparent time; so that if we find the sun to be upon the meridian of Greenwich, or it is 12 o'clock apparent time at Greenwich, it will, in one hour after of apparent time, be 15° to the west of Greenwich, in 2 hours 30° west, in 6 hours 90° , in 12 hours 180° , and so on, at which several times in succession the

sun will be upon the meridians of places, or it will be apparent noon, or 12 o'clock at places situated 15° , 30° , 90° , and 180° west longitude from the meridian of Greenwich; while the several corresponding hours of apparent time at Greenwich will be 1 o'clock in the afternoon, 2 o'clock, 6 o'clock, and 12 o'clock at night, or midnight.

Beyond the 180° west longitude, east longitude commences. The only difference in the two cases is, that places to the west of Greenwich are said to have their noon later, and their reckoned time earlier: those to the east have their noon earlier and consequently their reckoned time later than at Greenwich. Hence, if, when it is the hour of apparent noon at any place situated either to the east or west of Greenwich, the corresponding hour of apparent time at Greenwich could be ascertained, the longitude of that place might be directly found by turning the difference of their times into degrees and parts of degrees, reckoning 15° for every hour of apparent time, and for proportionate parts of an hour taking proportionate parts of 15° .

But, as it has been already explained, the variation of the apparent solar day makes apparent time ill adapted as a standard to refer to for the purpose of ascertaining the difference of longitudes by the difference of the apparent times at two different meridians: it is necessary, therefore, to show how the difference of the mean time at two different meridians may be substituted in its stead. It has been stated that, at four times in the year, the equation of time is nothing, or that at some particular moment of four days in the year the hour of mean time exactly corresponds with the hour of apparent time. Thus, it appears, from the Nautical Almanack, that on the 24th of December of the present year, at the hour of apparent noon, when the sun will be on the meridian of Greenwich, the apparent time will be in advance of the mean time at Greenwich by $20''.3$, that is, when it is 12 o'clock in the day, by the sun, it will want $20''.3$ to 12 o'clock by the watch; so that it will be then necessary to subtract $20''.3$ from the apparent time deduced from observation in order to ascertain the corresponding mean time at Greenwich for that day. But on the 25th of December, or at the hour of apparent noon at Greenwich on the following day, the apparent time will be *behind* the mean

time by $9''.8$, which quantity therefore must then be *added* to the apparent time to get at the mean; and the watch will be $9''.8$ past 12, when it is noon by the sun. Hence, as in the space between these two successive passages of the sun over the meridian of Greenwich, the equation of time, or the difference between apparent and mean time, has, from being subtractive, become additive, it has, at some moment of that interval, been 0, or has passed through 0; or, in other words, the mean time at Greenwich having overtaken the apparent time at that place, the hour of apparent time and that of mean time will, for some one moment, between the two successive noons, be the same. Now, as the difference between mean and apparent time, or the equation of time, depends upon the variable velocity of the sun in his apparent annual motion in the ecliptic, and upon the obliquity of the ecliptic or the angle it makes with the equator; these circumstances being independent of place, the equation of time is for all parts of the earth the same that it is at Greenwich at any given moment. Hence, as at some particular moment between the noons at Greenwich of the 24th and 25th of December, the equation of time is nothing, at that moment it is also nothing at every other place upon the globe, or the apparent and mean times are then every where exactly the same. But we have already proved that the longitude might always be determined by turning the *difference of the apparent times* at Greenwich and any other place into degrees at the rate of 15° to every hour of apparent time. At the particular moment, however, when the equation of time is 0, the difference of the apparent times is the same with the difference of the mean times at Greenwich and every other place upon a different meridian. Hence, at this moment the longitudes of all places may in like manner be determined by turning the *difference of mean times* at Greenwich and at all other places into degrees at the same rate of 15° for every hour of mean time. But what is true of mean time and of the difference of mean times at one particular moment, is true always, because mean time is not variable; so that the difference of mean times at Greenwich and all other places will always give the longitudes of places; and therefore by knowing on any day in the year the mean time at Greenwich, and also the corresponding mean time at

any other place, the longitude of that place will be found by converting the difference of their reckoned mean times into degrees, at the rate of 15° for every hour of mean time; it will be east longitude if the time at the place in question be later than the time at Greenwich, and west longitude if it be earlier.

All, therefore, that is required is to ascertain, 1st, the hour of mean time at the place, the longitude of which we wish to know; 2dly, the corresponding hour of mean time at Greenwich. Now the hour of mean time at any place may always be obtained by means of the corresponding *apparent* time, by adding to or subtracting from it the equation of time for the moment, which is given (or may be computed from what is given) in the Nautical Almanack. The hour of *apparent* time may always be found by means of an observed altitude of the sun, or, if the place be on land, by means of a sun-dial. The corresponding mean time at Greenwich may then be ascertained by a chronometer or time-keeper, adjusted and regulated so as to show Greenwich mean time. If, therefore, a time-piece could be made so perfect as always to show the mean time at Greenwich without error; or if its error in going were always the same, that is, if it gained or lost the same quantity every day, the longitude of places might be correctly found by such a chronometer.

This desirable object has not hitherto been attained: the most ingenious and accomplished mechanics, although prompted by the liberal rewards held out by the legislature to encourage their exertions, have failed of complete success. Time-pieces have, however, been made, which from their near approach to an equable rate of going, might appear to justify even sanguine hopes that at some period or other a *perfect* machine may be constructed; but it is highly improbable that these hopes will ever be realized. The imperfection of the human mind seems to oppose even a moral obstacle to the attainment of absolute perfection in any of its productions. In other works of art an apparent perfection may be obtained, because their defects are not visible to our senses, and we have no other means of ascertaining their existence; but in a machine which is to measure time, the smallest errors accumulate so as to become at last apparent, and in the daily equable motion of the earth on her axis,

nature herself affords a perfect measure of time, by a comparison with which the errors and defects of the measure constructed by human art cannot in the long run escape detection.

At sea, where other methods cannot be resorted to with facility, chronometers are generally used for finding the longitude; but the mere circumstance that the best chronometer is liable to error, and to error which may escape notice, makes it dangerous to trust to the chronometer alone; nor ought it to be relied on but under circumstances excluding the adoption of some of the other methods of finding the longitudes.

These methods, therefore, form the next subject of consideration.

There are various appearances from time to time taking place among the heavenly bodies, that afford the means of finding the longitude nearly. These appearances are the following: 1st, Eclipses of the moon; 2d, Eclipses of Jupiter's satellites or moons; 3d, Occultations or concealments of fixed stars, by the moon's passing over them; 4th, Eclipses of the sun; 5th, The passage of the moon over the meridian of the place the longitude of which is required; 6th, The same passage compared with that of one or more stars immediately preceding or following the moon, and having nearly the same declination; 7th, The distance of the moon from particular fixed stars or from the sun. There is also another method, of limited application, by means of artificial appearances upon the earth, as explosions of gunpowder made at one place and seen at another, the longitude of which is required.

The first and second and the last of these appearances are observed at all places where they happen to be visible at the same instant of *absolute* time. The difference, therefore, in the reckoned times, either mean or apparent, at two places where they are visible, is owing to the difference of their longitude. The time at Greenwich of eclipses of the moon and of Jupiter's satellites is previously computed and set down in the Nautical Almanack, and the corresponding time at the place whose longitude is wanted, being obtained at the moment of these appearances happening, the difference turned into degrees in the usual way is the longitude. By means of explosions of gunpowder or other signals made on the earth, the difference of the longitudes of any two

places not far distant from each other may be determined with very great exactness; the mean time for each place may be known by separate chronometers previously adjusted and regulated for the purpose; the difference of the times at the moment of the explosion or other signal, which is made at one place and seen instantaneously at the other, converted into degrees, will give the difference of longitudes. This method has of late become the more interesting from its having been adopted, in the course of the operations now in progress on the continent for measuring an arc of a parallel of latitude, as the best means of determining the longitude of the extremities of the arc. The space between the two extremities of this arc was divided into a great number of smaller arcs, all of such a length, that one of the extremities of each smaller arc might be made visible to an observer at the other extremity. At each point of division of the principal arc, were fixed stations, at which the requisite instantaneous signals were made and observed. The difference of times when these signals were made at one station and observed at another, gave the difference of longitudes of the extreme points of every smaller arc; and the sum of all the differences gave the difference of longitudes of the extremities of the principal arc. It is scarcely necessary to remark, that any thing answering the purpose of an instantaneous signal, may be used instead of explosions of gunpowder—such as the discharge of a rocket, or the sudden display or extinction of a lamp: a contrivance called a Heliostat (which is from two *Greek* words, and signifies any thing the position of which has some reference to the sun) has been employed on the continent: it has a strongly reflecting surface, and is placed in such a manner that the rays of the sun are reflected by it towards the desired point of observation; the reflection is then made to disappear suddenly by interposing a screen between the Heliostat and the distant spectator, and thus conveys an instantaneous signal.

The third and fourth methods, by occultations of fixed stars by the moon, and by eclipses of the sun, likewise depend upon the difference of the times at which these appearances take place at Greenwich (and which times are computed by means of tables); and of the times at which they are actually observed

to take place at the spot the longitude of which is required; but with this qualification, that as these appearances are not observed at all places at the same point of *absolute* time, the difference in the absolute times of their happening must be allowed for: thus, if at Greenwich the occultation of a certain fixed star by the moon, happen at six o'clock in the morning; and at some other place to the west of Greenwich it be observed to happen at midnight, thus making a difference of six hours in the reckoned times of the appearance, it will not follow that this is all due to the longitude, and that the place in question is 90° west longitude, for the occultation does not happen at both places at the same moment of absolute time; but the star is seen at the place in question for some time after it is hidden at Greenwich. This time, which being caused by parallax may be computed, must be added to the Greenwich time, computed from the tables; and then the difference between the resulting time at Greenwich, and the time at the place at the moment of the occultation *there*, will give the true difference of corresponding reckoned times between that place and Greenwich; and from this difference the longitude may be deduced. The difference in the absolute time of these appearances occurring at different places, is owing to the sun and fixed stars shining by a light of their own, and to the moon's parallax.

The fifth method is by means of the moon's passage over the meridian.

If the sun and moon be upon the meridian of Greenwich together, on any particular day, on the following day when the sun is again on that meridian, the moon will be considerably to the east of it; and some time will consequently elapse before the moon reaches the meridian of Greenwich after the sun has left it. This *easterly* separation of the moon from the sun after they have been together, is caused by the moon's quicker motion in her orbit or course round the earth; and the time which elapses between the passage of the sun over the meridian of Greenwich, and that of the moon, is called the moon's retardation. The moon's motion in her orbit continuing, the distance between the sun and moon continually and gradually increases; so that if the moon's retardation be of a certain amount at the time of its passing the meridian of Greenwich, the retardation

at a place to the *west* of Greenwich will be of a greater amount, in proportion to the time that is required to bring the moon from the meridian of Greenwich, to the meridian of the place to the west of Greenwich. Hence, as the increase of the moon's retardation is for 24 hours proportional to the times in which it is produced, by knowing the retardation at two different meridians, and the time during which the retardation at one of the meridians has been produced, the time during which the greater retardation at the other meridian has been produced, may be found by the rule of three. Thus, suppose that the sun and moon having been upon the meridian of Greenwich together on one day, the retardation of the moon at Greenwich on the following day, or in 24 hours, is 52'; that at a place to the west of Greenwich the retardation of the moon is observed to be 57', or 5' more than it was at Greenwich; then we shall have this proportion; as 52' : 57' :: 24 hours : 24 hours + the additional time necessary to produce the additional retardation of 5'. This additional time is due to and expresses the difference of the longitudes, and 24 hours correspond with 360° of longitude. Hence, 52' of time : 57' of time :: 360° : 360° + difference of the longitudes; and as in this case we have taken the meridian of Greenwich, the longitude of which is 0, we shall have 52' of time : 57' of time :: 360° : 360 + longitude of the place; or the longitude of the place

is equal to $360 \times \frac{5'}{52'}$ of time, and ex-

pressing the time in parts of degrees at the rate of 15° to an hour, the longitude is obtained. Hence generally the longitude of a place is equal to 360°, multiplied by the difference between the retardation of Greenwich and the retardation of the place the longitude of which is required, divided by the increase of the retardation at Greenwich in the 24 hours preceding the time of observation. The increase of retardation at the place the longitude of which is required, is known from observation. The increase of retardation at Greenwich, for the 24 hours preceding, may be found by means of the Nautical Almanack.

The principle of this method is applicable to the fixed stars as well as to the sun; the only difference being, that the moon's retardation is greater with respect to the fixed stars, as they have

none of the daily easterly motion which the sun has in its apparent yearly path in the heavens. The application of this principle to the fixed stars for finding the difference of the longitudes of two places, was first successfully made by M. Nicolai, a distinguished astronomer, at Manheim, and is now very generally practised on the continent. Mr. Francis Baily, in his valuable paper on this subject, lately published in the *Memoirs of the Astronomical Society of London* (vol. ii.), observes, "That already at several observatories, the observers have been enabled to determine their difference of meridians in a few months with as much accuracy as they formerly could in as many years." The improvement introduced by M. Nicolai consists in the choice of those stars which have very nearly the same declination or distance from the equator as the moon, and which pass the meridian very soon after, or a little before the moon. The advantages of the method are to be found in avoiding a great number of errors and troublesome calculations, which in practice were found to detract from the value of other methods, and in the frequency with which observations may be made, being every night that the moon is visible. It was employed with very great success by Lieutenant Foster on Captain Parry's last voyage but one, in determining the longitude of Port Bowen in Prince Regent's Inlet. His observations have been calculated and compared with those made at the observatories of Greenwich and Dublin, and by the late Colonel Beaufoy at Bushey Heath; and the results, which will appear in a volume of the Astronomical Society's *Memoirs*, show, as far as one example can do so, the great value of this method of determining the longitude on land.

None of the previous methods, however, (except that which consists in the use of chronometers,) are adapted to the situation of a person on board a ship. The late Astronomer Royal, *Dr. Maskelyne*, in his Preface to the *Nautical Almanack*, observes, "It was hoped that some means might be found of using proper telescopes on shipboard to observe these eclipses [the eclipses of Jupiter's Satellites]: and could this be effected, it would be of great service in ascertaining the longitude of a ship from time to time. In my voyage to Barbadoes, under the directions of the *Commissioners of Longitude*, in 1763,

I made a full trial of the late *Mr. Irwin's* marine chair proposed for the purpose, but could not derive any advantage from the use of it; and considering the great power requisite in a telescope for making these observations well, and the violence as well as irregularities of the motion of a ship, I am afraid the complete management of a telescope on shipboard will always remain among the desiderata."

The longitude may, however, be found at sea, when the moon is visible, by the observed distance of the moon either from the sun or from nine of the principal fixed stars mentioned in the *Nautical Almanack*. This distance is observed by means of a Hadley's Sextant. In consequence of the moon's quick motion in her orbit she is every moment changing her situation in the heavens with respect to the sun and stars. Her distance, therefore, from the sun, or a particular star, is at one moment of time different from what it was at the previous moment, and what it will be at the next; so that a particular or given distance is proper or due to a given moment, which moment will be expressed or reckoned differently at different meridians, according to the apparent time of day. This difference in the apparent times, being therefore due to the difference of meridians will, converted into degrees, give the longitude. The distance of the moon from the sun, and from nine principal fixed stars, is given in the *Nautical Almanack*, for every three hours of Greenwich time. This distance is such as it would appear at the centre of the earth; allowance having been made in computing the distance given in the *Almanack* as well for parallax as for refraction. The *observed* distance at the place the longitude of which is required, is in a similar manner to be reduced to the centre of the earth by correcting for the moon's and sun's parallax, and for refraction. The apparent time, at the place and moment of observation, is obtained in the usual manner, by taking the contemporary altitude of the sun or star. The difference between this apparent time and the apparent time at Greenwich, given in the tables as corresponding to the *same distance*, converted into degrees, will be the longitude of the ship. This method of finding the longitude is called the lunar method; it will generally give the longitude to

within twenty miles, frequently much nearer; it was brought into general use by the exertions of Dr. Maskelyne, who, on his voyage to St. Helena, in the year 1781, employed it with great success.

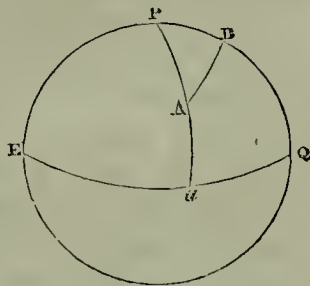
The latitude and longitude of a place having thus been ascertained, the exact position of that place on the surface of the globe is determined.

CHAPTER VII.

To find the Direct Distance between any two Places—Decrease of Degrees of Longitude.

KNOWING the latitude and longitude of two different places, the shortest distance between them, measured on the surface of the globe, may be found. Let A and B (*fig. 8.*) be two places upon

Fig. 8.



the earth's surface, E a Q the equator, P the pole, A a the latitude of A, B Q that of B; a Q, which is the difference of their longitudes, is known, as the longitudes of both places are supposed to be known; then A B, being the arc of a great circle passing through A and B, is the shortest distance, and may be found as a side of the spherical triangle A B P by spherical trigonometry. With a trifling inaccuracy, the distance, A B, may also be determined mechanically, by means of a common terrestrial globe and a pair of compasses. The opening of the compasses given by applying the extremity of either leg to each place on the globe, will be the measure of that arc of a great circle which lies between the two places. The number of degrees contained in this arc may then be ascertained by applying the compasses, thus open, to any graduated great circle on the globe, or one which has the degrees marked, such as the equator or ecliptic. The number of degrees thus found, being turned into geographical miles, at the rate of 69.044 miles to

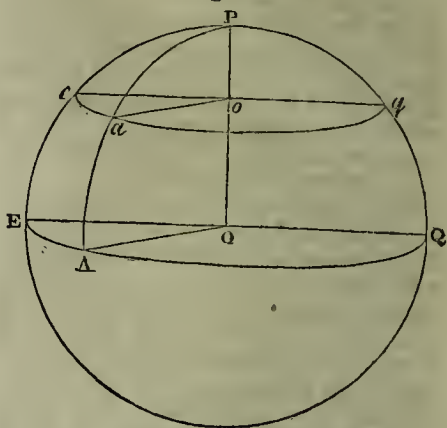
a degree, will give the actual distance in miles. Thus the direct distance between Paris and Buenos Aires is $99^{\circ} 24' 35''$, which is equal to 99.41° nearly. Multiplying this by 69.044, will give the direct distance in miles, which is equal to 6863.66404 miles, or 6863 miles 5 furlongs nearly.

It has just been taken for granted that the shortest distance between two places on the globe is the arc of a great circle. This may be made evident by a few simple considerations. The plane of a great circle passes through the centre of the globe; that of a small circle does not: the radius of a great circle, therefore, is greater than that of a small one, and consequently the curvature or bending of the former is less than that of the latter. And as a straight line is the *shortest* distance between two points, so of two *curved* lines joining two points, that which is most like a straight line, *i. e.* the *less curved* line of the two, is the *shorter*; and therefore the arc of a great circle, lying between two places on the globe, is the shortest distance.

If we suppose, (as hitherto we have done,) that the earth is perfectly spherical, it is evident that a degree of latitude, being the 360th part of a meridian, which is always a great circle, must be everywhere of the same length. It is otherwise with degrees of longitude: except for places upon the equator, a degree of longitude is an arc of a small circle, and is less than a degree of longitude measured upon the equator, which is a great circle. And the magnitude of a degree of longitude becomes gradually less in proportion as the distance from the equator increases, or as the latitude increases. The radii of the circles on which the longitude is measured (called the parallels of latitude) decrease from the equator to either pole; so that the circumferences of parallels of latitude decrease in like manner: but the circumference is always equal to the number of degrees into which it is divided, multiplied by the length of each degree; and as the number of degrees is the same in all circles, the length of each degree varies with the circumference, and must, therefore, decrease from the equator to the pole. The precise measure or law of this decrease may be proved in the following manner. Let (*fig. 9.*) the arc *AE* represent a degree of longitude upon the equator *EQ*; *ea* a corresponding arc of a de-

gree of longitude, measured upon the parallel of latitude *eaq*, in latitude *A*.

Fig. 9.



Then, as the length of a degree varies as the circumference, and the circumference as the radius, we shall have the length of *AE* to that of *ea* at latitude *A*, as radius *AO* is to radius *ao*, where *AO* is the radius of the earth, and *ao* is the radius of the small circle *eaq*, the plane of which is parallel to the plane of the equator. In plane trigonometry, the radius *ao* is called the cosine of the arc *Aa*, or the cosine of the latitude *A*; hence the length of a degree of longitude at the equator is to the length of a degree at a given latitude *A*, in the proportion of the radius of the earth to the cosine of the latitude; and as the degree at the equator and the radius of the earth are invariable, the length of a degree of longitude varies as the cosine of the latitude.

CHAPTER VIII.

Oblate-Spheroidal Figure of the Earth —Cause of this Figure—Centrifugal Force.

THE various phenomena which indicate the nature of the earth's shape have been already described. They are sufficient to establish in a general way the roundness of the earth, but they are at the same time of that vague and indefinite character, as to be incapable of solving the more difficult problem of the earth's specific and exact shape. In order to determine this, it has been necessary to resort to experiments of an extremely delicate and tedious description, and to call in the aid of complex mathematical calculations founded upon the facts which the experiments have brought to light. The attention of some

of the most eminent philosophers of Europe has for many years been given to this subject ; and although the true figure of the earth cannot be considered as even yet determined with all the precision that is desirable, it is now conclusively proved that the earth is not a perfect sphere, but of an oblate-spheroidal * form, bulging out at and about the equator, and flattened at the poles ; and that the equatorial diameter is longer than the axis or polar diameter. The excess of the equatorial above the polar diameter represents, when compared with the whole diameter, the quantity by which the figure of the earth deviates from a perfect sphere ; it is called the earth's ellipticity or compression.

The discovery and proof of the earth's elliptical shape, and the laborious undertakings engaged in for determining the quantity of it, occupy some of the most interesting pages in the history of science. It is not perhaps to be much regretted that the person who first started the idea of the earth's spheroidal shape should be unknown. The first notion of it was in all probability nothing better than one of those happy conjectures which have been verified by subsequent proofs ; but the name of Newton is as intimately allied with the discovery of the earth's true figure as with that of universal gravitation. In both cases the idea had been already entertained by several philosophers, but it was Newton who redeemed the truth from conjecture, and established it upon the basis of demonstration : with respect to the figure of the earth, he proved, from admitted principles and facts, that it must of necessity be an oblate-spheroid, and he assigned a ratio between the equatorial and polar diameters.

The true figure of the earth is that which the particles composing it must assume, in order to be in a state of equilibrium or rest : the figure, therefore, depends essentially upon the forces which act upon these particles. The principal of these forces is the mutual attraction which subsists between the particles themselves. Any other force which acts in a different direction to this principal force, or with unequal intensity upon different particles, is a disturbing force ; it disturbs and deranges that state or figure which the whole mass of

the earth would assume if affected only by the mutual attraction of the component particles.

The method of conducting the investigation of the true figure of the earth, is one which is very usual in mechanical philosophy. The most simple and striking characteristics of the problem are singled out and considered alone, and the result obtained from them is afterwards varied and modified by the introduction of such minor and more complex conditions as are suggested by the problem in its true and practical form. In this manner, in the science of mechanics, the first principles and ground-work truths are ascertained, upon the supposition that the parts of machines are without weight, and that there is no such thing as friction, and the effect due in the practical result to these and other circumstances is estimated afterwards.

In attempting to determine the true figure of the earth, it has accordingly been assumed in the first instance, that the earth is a body consisting only of fluid particles which move easily among themselves, and that the density of the particles, or the quantity of matter contained in the same space is the same throughout, and that the earth is in a state of rest. If this were the case, the only form in which equilibrium could take place among the particles which compose the earth, and which exert a mutual and equal attraction upon each other, is a perfect sphere. This may be exemplified by adverting to the familiar circumstance of drops or globules of water, or of quicksilver, upon a perfectly smooth and dry plain ; by the force of mutual and equal attraction, the particles of which they consist, dispose themselves in a globular form. It is true, that the form of these drops is not perfectly spherical, but is rather flattened at the top ; because the force of gravity which acts without an equal resistance upon the upper particles, makes them press down upon the lower, and thus deranges the effect which would be produced by their mutual attraction alone : but the fact is sufficient as a popular illustration of this conclusion, — that fluid particles of an equal density, not affected by any external and partial force, would assume the form of a perfect sphere as that of a state of equilibrium.

Now in this statement it is evident, that three conditions have been introduced which are not verified in the

* An oblate spheroid is a solid body which may be conceived to be formed by the revolution of an ellipse or oval about its lesser axis.

the particles lying under the equator move in the circle of the equator; all other particles between the equator and the poles move in circles parallel with the equator. Hence, particles moving in the equator have the greatest velocity and the greatest centrifugal force; those nearer the equator a greater velocity and a greater centrifugal force than those particles which are more distant from the equator. Moreover, the direction of the centrifugal force communicated by this motion is always opposite to the direction of the radius of the different circles in which the particles move; thus if Ld (fig. 10), be the radius of the circle in which a particle at L moves, the direction of the centrifugal force at L will be La , and the direction of the centrifugal force at Q , in the equator will be Qq , QC being the radius of the equator and also of the earth. Now gravity or the centripetal force is always in a direction perpendicular to the surface, and therefore it is only at the equator, that this is exactly in an opposite direction to the centrifugal force. At L for instance, if La be taken as in the direction, and as also representing the quantity of centrifugal force there, it may be resolved in two directions ab , Lb , one of which only, ab , is directly opposed to the force of gravity, while the other is perpendicular to the direction of gravity, and is a tangent to the surface, and does not diminish the force of gravity. Hence it follows, that in the equatorial regions, where the directions of gravity and of the centrifugal force are both perpendicular to the surface, the two forces become altogether opposed to each other, and the whole amount of the centrifugal force of rotation takes effect in diminution of the force of gravity. But in parts distant from the equator (as at L), a portion only of the centrifugal force (viz. ab), and that in its diminished state, acts in opposition to the force of gravity; the rest of it (viz. Lb) is in the direction of a tangent, and tends towards the equator.

In order, therefore, that equilibrium may now be preserved among the component particles of the earth, a great accumulation of particles takes place in the equatorial regions, which by their number compensate their deficiency in gravitating force. And this effect is increased by that part of the centrifugal force acting between the poles and the equator, which is in a tangent direction

to the earth's surface, and which tends to thrust down the particles on which it acts towards the equator. Hence the equatorial regions are elevated above the polar, and the height of all other intermediate parts is in some proportion of the distance of those parts from the equator. This is the alteration produced in the figure of equilibrium, by the diurnal rotation of the earth upon its axis.

But the earth being neither altogether fluid, nor of the same density throughout, we must introduce some qualifications into the result we have just arrived at. The earth being partly solid, the particles of which it is so far composed do not move easily among themselves, but have an attraction of cohesion which opposes a certain resistance to the operation of the centrifugal force caused by its motion of rotation. This neutralizes and destroys part of the centrifugal force, and makes the earth's ellipticity to be less than it would be if the earth were altogether fluid. But the centrifugal force is not altogether destroyed by the attraction of cohesion; for it must have elevated even the solid parts of the equatorial regions; were it not so, the waters of the ocean, not being restrained in their motion by the same attraction of cohesion, would all have set towards the equator in order to restore the equilibrium which, by the diminution of the centripetal force of gravity there, had been disturbed, and would thus have overflowed the land at the equator and left the polar regions dry. It may here be remarked, that the two constant currents in the sea, which are observed to set from both poles towards the equator, may perhaps be accounted for, by the action of that part of the centrifugal force which is in the direction of a tangent to the earth's surface and towards the equator. The waters of the sea, having no attraction of cohesion, would obey the impulse of this force freely, as it is not opposed to the force of gravity. The westerly set of the same currents may be ascribed to their continually advancing into regions which have a greater easterly motion of rotation.

The effect produced by the varying density of the earth, which increases towards the centre, has been proved by Clairaut, a celebrated French mathematician, to be a diminution of the oblateness of the earth, so that from this

cause the height of the equatorial regions is somewhat less than on the supposition of an equal density; which is contrary to what Newton supposed would be the effect of an increase of density towards the centre.

The result of Newton's inquiry into the figure of the earth was, that the equatorial diameter of the earth is to the polar as 230 : 229; from this ratio the ellipticity of the earth would be expressed by the fraction $\frac{1}{230}$; or the polar diameter would be less than the equatorial by the 229th part of the whole, and the equatorial regions would be about 17 miles higher than the polar.

A very simple mathematical process will enable us to exhibit the value of the centrifugal force at any point of the earth's surface.

Let C (*fig. 10*), be the centre of the earth, Pp the polar axis, EQ the equator, L a particle acted upon by the centrifugal force at any latitude LQ or λ ; from L let fall Ld perpendicular to the polar axis, Ld will be the radius of the circle of rotation at latitude λ , and CQ will be that of the equatorial circle of rotation, and is the same with the radius of the earth.

Now the whole amount of centrifugal force varies as the velocity; for motion or velocity is the producing cause of it, and the velocity of rotation of different parts of the earth's surface varies as the circle of rotation, and therefore varies as the radius of that circle:—hence the centrifugal force at any point L, varies as Ld, which is the sine of PL, or the complement of the latitude, or the *entire* centrifugal force varies as the cosine of the latitude.

Take La to represent the *whole* centrifugal force at L, resolve this in directions Lb, ab, perpendicular and parallel to that of gravity: then ab is the only part of the centrifugal force which directly opposes the force of gravity. From L let fall Ll, perpendicular to CQ, then Lab and LCl, are similar triangles, and $ab : La :: cl : CL$, so that ab, or the centrifugal force opposed to gravity, is equal to $La \times \frac{cl}{CL} = La \times$

$\cos. \lambda =$ whole centrifugal force at L $\times \cos. \lambda$. Now the whole centrifugal force we have shown to vary as the $\cos.$ of the latitude; therefore whole centrifugal force at L : centrifugal force at the equator :: $\cos. \lambda : 1$, for at the equator the latitude = 0 and $\cos. 0 =$ radius; but the centrifugal force at the

equator is found to be $\frac{1}{230}$ part of the force of gravity there, or is equal to $\frac{g}{230}$, if g represent the force of gravity at the equator. Hence the whole centrifugal force at L = $\frac{g}{230} \cos. \lambda$, and substituting this in the equation for the centrifugal force at L, opposed to gravity, which we may call F, $F = \frac{g}{230} \cos. \lambda$, and varies as $\cos. \lambda$.

The value of the other part of the force Lb, which acts in a tangent to the surface, may now be easily

$$\begin{aligned} \text{found, for } Lb &= \sqrt{La^2 - ab^2} = \\ &= \sqrt{\left(\frac{g}{230} \cos. \lambda\right)^2 - \left(\frac{g}{230}\right)^2 \cos.^4 \lambda} \\ &= \frac{g}{230} \cos. \lambda. \sqrt{1 - \cos.^2 \lambda} = \frac{g}{230} \cos. \lambda. \sin. \lambda. \end{aligned}$$

CHAPTER IX.

Oblate Figure of Jupiter, Saturn and Mars—Pendulum Experiments.

IN the foregoing chapter we have explained the causes which have produced the earth's ellipticity. We now proceed to the various evidences of this fact which have been derived from observation and experiment.

As the same causes must, under similar circumstances, produce similar effects, it was just to suppose that if the reasoning by which the earth's ellipticity is established be correct, the other planets of the solar system would exhibit the like appearance of a flattening at their poles and a bulging out of their equatorial parts; for their component particles are under similar circumstances of mutual attraction, of equilibrium, and of rotation about an axis*. This was the rather to be looked for, because of the analogy or resemblance which is to be traced in the principal features of the solar system. Thus, among other analogies, the orbits of all the planets revolving round the sun are elliptical; their periodic times, or the times of their revolutions, are in proportion to the cubes of their mean distances from the sun, and the forces by which they gravitate towards the sun are as the squares of those distances. The supposition of an ellipticity in the planets similar to that which is observed in the earth, was first verified in the planet Jupiter. This planet completes his

* We must except from the generality of this remark the planets Uranus, or Georgium Sidus, which is too distant, and Juno, Vesta, Ceres, and Pallas, which are too small to admit of any observations by which to ascertain whether they revolve about an axis or not.

daily rotation about his axis in 9 hours and 56 minutes; the centrifugal force exerted upon him is therefore considerably greater than that which affects the earth; and the density of Jupiter is less than that of the earth. Hence the figure of Jupiter ought to be much more oblate or compressed at the poles than the earth is. This was found to be the case by an astronomical admeasurement of his diameters. The equatorial diameter of Jupiter is to the polar as 13 : 12, and is longer than the polar by about 6230 miles. Saturn and Mars exhibit the same oblate-spheroidal appearance. The other planets do not offer facilities for ascertaining the effect of a centrifugal force upon them. With respect to the moon, her motion about her axis is too slow (being performed in $29\frac{1}{2}$ days) to produce enough centrifugal force to make a difference in her diameters, arising from this cause, observable. She has, it is true, a spheroidal form, but this is owing to the attraction of the earth, which is four times greater than what is caused by her motion of rotation.

The horizontal parallaxes of the moon furnish another though subordinate proof of the earth's spheroidal form. If the earth were a perfect sphere, these parallaxes would be the same for all places upon the earth's surface—if a spheroid, they would be different at different places; and this is actually the case; so that the same heavenly body which by her eclipses indicates the earth to be round, by her parallaxes shows it to be not truly spherical.

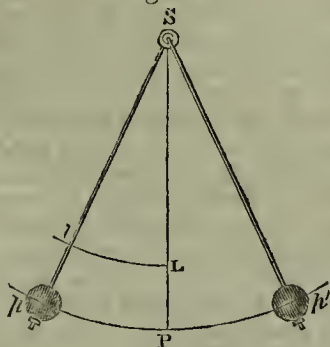
But the more direct evidence of the existence of a centrifugal force and of the earth's ellipticity, and the means of determining the amount of it, are to be looked for in the experiments made with the pendulum, and in the measurement and comparison of the lengths of degrees of the meridian in different latitudes.

The nature of the evidence afforded by pendulum experiments may be explained by a reference to a few very obvious principles.

The centrifugal force caused by the earth's rotation is (we have seen) greatest at the equator and decreases towards the poles; this centrifugal force, either in its whole quantity or in part, acts in a direction opposite to that of gravity, and therefore, being greatest at the equator, it diminishes the force of gravity at the equator by the greatest

quantity. Hence, bodies are lightest at the equator, and their weight gradually increases as we proceed towards the poles, where it is greatest. The pendulum of a clock performs its vibrations, or swinging motion to and fro, by being acted upon by the force of gravity.

Fig. 11.



If, therefore, two pendulums $S p$, $S p'$ (*fig. 11*), be taken of the same length, and the same substance or density, and be hung from the same point S , and $S P$ be the vertical position of both, and they be made to fall from equal distances from P , it is evident they will move through the equal spaces $P p$ and $P p'$ in exactly the same time, because the force which causes their descent (namely that of gravity) is equal in both cases. But if one of these pendulums ($S p$) be made to swing at the equator (being let fall from the same height as before), and the other ($S p'$) at some place between the equator and the poles (say at Paris), the time of $S p$ arriving at P will be longer than the time in which $S p'$ will move through the same space; because the force of gravity, which causes and accelerates the motions of both, is less at the equator than at Paris. But if we shorten the equator pendulum by some determinate quantity, it may be made to perform its vibrations in the same time with the Paris pendulum; for it will then have to describe a similar arc of a smaller circle or a less space, and a less accelerating force will enable it to describe this space in the same time. Such is the effect of the centrifugal force upon the vibrations of the pendulum in different latitudes. The existence of it was first detected by Richter, a French astronomer, who, in the year 1672, was sent to make astronomical observations in the island of Cayenne, which is not quite 5° north of the equator. Sir Isaac Newton has, in his Prin-

cia, described the particulars of the discovery. He says, that when Richter was, in the month of August, observing the transits of the fixed stars over the meridian, he found his clock to go slower than it ought, in respect of the mean motion of the sun, at the rate of $2' 28''$ a day. Therefore, setting up a simple pendulum to vibrate in seconds, which were measured by an excellent clock, he observed the length of that simple pendulum; and this he did over and over every week for ten months together; and upon his return to France, comparing the length of that pendulum with the length of the pendulum beating seconds at Paris, he found it shorter by $1\frac{1}{4}$ line.* In accounting for this difference in the length of the two pendulums, Newton allowed $\frac{1}{4}$ th of a line as the utmost that could be attributed to the extension of the pendulum by the heat of the climate; the difference, or $1\frac{1}{2}$ line by which this pendulum was shorter than the Paris one, was made necessary by the less gravity of bodies at and near the equator. From this fact he obtained the same conclusions he had before deduced from theory alone, namely, that the equatorial diameter of the earth was greater than the polar by the 229th part of the whole diameter. Since that time observations upon the lengths of pendulums beating seconds in different latitudes, have been made with great assiduity by scientific men of all countries; but recent experiments tend to show that the earth's ellipticity is not so great as $\frac{2}{25}$; the fraction $\frac{2}{38}$ is the value which results from the latest investigations.

CHAPTER X.

Length and Measurement of Degrees upon the Earth's Surface.

THE remaining evidence of the earth's ellipticity is the different lengths of degrees of the meridian arc in different latitudes.

A degree of a meridian is that portion of it which must be travelled over, in order to change the altitude of any particular star, by the 360th part of the imaginary meridian circle in the heavens: if the spaces travelled over in different parts of the same terrestrial meridian, in order to produce this change in the altitude of a star, be not equal

to one another, the terrestrial meridian cannot have the same curvature in every part, and is therefore not a circle; and consequently, the figure of the earth on the surface of which the meridian is traced cannot be a perfect sphere. Now it has been found by trial, that to raise the pole star by a quantity equal to a celestial degree, an observer must travel over a greater and increasing space as he proceeds from the equator to the pole. Hence it follows, that the degrees of a meridian line on the earth, or degrees of latitude, gradually increase from the equator to the pole; the meridian has, therefore, less curvature at the poles than at the equator, and the earth upon which it is traced is not a perfect sphere, but is flattened at the poles.

It is not to be immediately concluded from this that the earth is a regular oblate-spheroid; but it has been justly remarked, that, though it is only by experiment that the true figure of the meridian can be discovered, it has been found necessary to assume hypothetically (or by way of supposition), that its figure is the curve next in simplicity to the circle, viz. the ellipse, and also to suppose that the earth is a spheroid generated by the revolution of this ellipse about its shorter axis; for, in many complex cases, this mode of getting near the truth by probable suppositions, has been found the simplest and most convenient to be pursued; the only caution to be observed, is to submit the supposition first made to the test and correction of actual experiment. This caution has been carefully attended to in the matter we are discussing, by the measurement and comparison of degrees at various parts of the earth's surface.

In the measurement of a degree or of an arc of a meridian, many difficulties present themselves in the way of an *actual* and *mechanical* measurement. The general features of a country are such as to make any attempt of this kind unadvisable; a great number of almost conjectural allowances must be admitted into such a plan of operations, which forbid our placing much confidence in the result. The first modern measurement, having any just claim to accuracy, was, however, made in this manner. This was the measurement by Norwood, in 1635. The arc measured was that part of the meridian which lies between London and York. The difference of the latitudes of these cities was first ascertained; this gave the

* A line is a small French measure equal to the twelfth part of an inch.

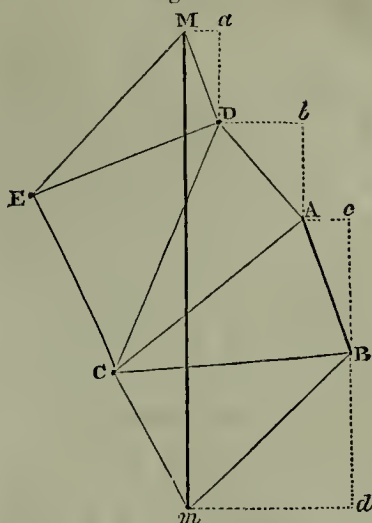
number of degrees in the arc to be measured; the distance between the two cities was then actually measured; and the turnings and windings of the road, and the ascents and descents, were allowed for afterwards. The length of a degree thus determined was 122,399 English yards; which, notwithstanding the extreme liability of this method to error, is not very far from the truth; according to the latest determinations, the length of a degree between these latitudes is 121,660 yards. The only other instance of the *actual* measurement of an arc of the meridian is that of Messrs. Mason and Dixon. They measured an arc of the meridian of 179,359.313 English yards in length, in the state of Pennsylvania. An account of this measurement is given in the *Philosophical Transactions* for the year 1768. The other and more accurate mode of finding the length of a degree, is a combination of actual measurement and of trigonometrical calculations founded upon it. All geodesical* operations (as they are called) are now conducted according to this method. Two places are selected which lie under the same meridian, or nearly so; the difference of their latitudes, which gives the number of degrees in the arc to be measured, is then ascertained with the utmost precision. A base line of a few miles in extent, and at some little distance from the meridian arc, is then very carefully measured; this is the only *actual* measurement which need be made. The extremities of this base line are connected with the extremities of the meridian arc, by imaginary triangles; the sides of which are not measured, but, by the aid of the base line, and by means of the angles of the triangles, which are all ascertained by an instrument for measuring angles, are determined by trigonometrical computation. This mode of ascertaining the length of the meridian will, however, be set in a clearer light by following the steps of the process in the subjoined figure.

Let (fig. 12) Mm represent a meridian arc; the difference of latitudes of the two extremities, M and m , being found, the length of a degree in the latitude of M and m will be the length of the whole arc divided by the number of degrees contained in it.

A level plain is then to be selected,

on which a base line AB is measured; the two extremities of this line are to

Fig. 12.



be connected with the two extremities of the arc Mm , by a series of triangles. For this purpose convenient stations are fixed upon, such that the three stations situate in the three angles of every triangle may be visible to each other. Let C, D, E , be the stations fixed upon, these are supposed to be connected together, and with the points M, m , by the imaginary lines which form the various triangles ABC, BCm, ACD, CDE , and DEM . Then the angles by which the two stations C and B , appear to be separated from each other when viewed from the station A , is observed. This observation gives the angle CAB of the triangle ABC ; the other angles of this triangle are observed and determined in the same manner, and the side AB , which is the base line, being known from measurement, the other two sides AC, BC , may be computed by plane trigonometry. By this means we obtain a side of each of the triangles BCm, ACD , and are enabled to continue the process without measuring any more sides. The angles of these triangles are measured as in the case of the first, and their sides are ascertained in like manner by trigonometry; and by proceeding in a similar way in the resolution of the whole series of triangles, the sides and angles of all are determined. The remaining step in the field proceedings is to ascertain the inclination of the lines MD and Bm , to the meridian arc; astronomy affords the means of doing this. From the data

* From two Greek words, which combined, signify a dividing or apportioning of the earth.

furnished by these operations, the length of the arc Mm is determined in the following manner:—from M and D , draw the lines Ma perpendicular to Da , parallel with the meridian line, meeting each other in a ; Db , Ab , Ac , Bc , md , Bd , are also drawn so as to be respectively perpendicular to and parallel with the meridian. Then it is evident that the length of Mm is equal to the sum of the lengths of aD , bA , cB , Bd , which are found thus:—the inclination of MD to the meridian having been already determined by an astronomical observation, the angle DMa in the right-angled triangle DMa is known from it, and the side MD is also known, so that Da (which is equal to $MD \times \sin. DMa$) may at once be computed by trigonometrical tables. In a similar manner the sides bA , cB , dB are computed, and the sum of the whole gives the length of the meridian arc Mm , and the length of a degree is the length of the whole arc divided by the number of degrees contained in it.

Picard was the first person who measured an arc of the meridian by this method. The operation was performed in the year 1670; the arc commenced near Paris, and extended northward; the result of the measurement gave, as the length of a degree in latitude $49\frac{1}{2}^\circ$, 121,627 yards, which differs only 35 yards from what is now considered as the most exact length; an accuracy which is justly supposed to be quite accidental.

Since this period arcs of meridian lines have been measured in various countries, as well in intermediate latitudes between the equator and the north pole, as near both the equator and the pole. The following table represents the length of a degree in different latitudes as determined by the five most approved measurements:—

	Latitude.	Degrees in Toises.	Degrees in Fathoms.	Country.
1	$0^\circ 0' 0''$	56749	60480.2	Peru.
2	$11 0 0$	56755	60486.6	India.
3	$45 0 0$	57011	60759.4	France.
4	$52 2 2$	57071	60826.6	England.
5	$66 20 10$	57192	60952.4	Lapland.

The following particulars will show at once the accuracy which now distinguishes geodesical operations, and some of the means taken to ensure it:—

The first base in the English measurement, of which the result is given in the above table of degrees, was about five miles in length, and was measured upon

Hounslow-heath with a steel chain of exquisite workmanship. The same base had been measured three years before by General Roy, with glass rods, and the two measurements (in a length of five miles) differed only $2\frac{3}{4}$ inches. The French base was measured with rods of platina, that in Lapland with rods of iron, and an allowance was made for the changes of temperature affecting the length of the rods in the course of the operation. In a previous measurement in Lapland, the French astronomers, in order to guard against the extreme contracting effect of cold upon metals, employed rods of deal; this was the more necessary in that measurement, as it was performed in the depth of winter, and the frozen surface of a river was selected for the base line, with a view to obtain as level a plain as possible. It is usual also, in order to prove the correctness of the geodesical process, to measure, towards the conclusion, what is called a base of verification. We have already stated that all the sides of the series of triangles (with the exception of the base line AB , which is a side in the first triangle) are not measured but computed: to verify all the previous steps in the process, the length of one of the sides of the triangles, as it has been deduced from computation, is compared with its length determined by actual measurement. The side of the triangle thus measured is called a base of verification, and is taken as far distant from the first base as circumstances will admit. In the French operations the base of verification was distant between four and 500 miles from the first base, and was 7 miles in length, and yet the difference between its computed length and that obtained from its actual measurement did not amount to 12 inches.

From an inspection of the table before given, it appears that the length of a degree from the equator to the pole increases—the curvature therefore diminishes, and the earth is not a sphere but is flattened at the poles, and the polar diameter is less than the equatorial; and although the various modern measurements may not, on a comparison one with another, agree in giving to the difference of the two diameters precisely the same value, yet they all ascertain the fact of the polar diameter being less than the equatorial, and that a degree increases towards the poles; and this establishes the oblate-spheroidal figure of the earth.

The value of the compression or the fraction expressing the difference between the two diameters, as deduced from a comparison of the lengths of a meridional degree in different latitudes, determined by the most approved measurements, has been lately shown by Professor Airy, in a paper in the last volume of the *Philosophical Transactions* to be $\frac{1}{273.6}$, that is, the polar diameter is less than the equatorial by the 273.6th part of the whole diameter.

Operations are now being carried on, on the continent, which have for their object the more precise determination of the fraction of ellipticity, and of the compression of the earth. The measurement of an arc of the parallel of latitude 45° , of 15° or 16° in extent has been already accomplished. One extremity of this arc is at Marennes, on the west coast of France, and a little to the north of the Garonne, and traversing France, Piedmont, and the northern parts of Italy, its other extremity is at Fiume, in the Austrian dominions, and on the eastern shores of the Adriatic. The value of the ellipticity as deduced from these operations is $\frac{1}{292.3}$. We have already stated that the pendulum experiments give $\frac{1}{288}$. This similarity in the results afforded by such very different kinds of investigation is a strong argument in favour of the general correctness of both.

The mean degree of a meridian or the degree the length of which is as much greater than that of a degree at the equator, as it is less than that of a degree at the poles, is in latitude 45° , which is the mean latitude between the equator and the poles. Its length, according to the French measurement, is 60759.4 fathoms, or 12158.8 yards. The circumference of the elliptic meridian is found by multiplying the mean degree by 360, and is equal to 24855.84 miles. The circumference of the equator is 24896.16 miles, and is not quite 41 miles longer than the elliptic meridian.

The French measurement, in 1792, was undertaken with a view to obtain a standard measure of length, to serve as the basis of a new system of weights and measures. According to this new system, the unit, or first element of linear measure, is called a metre; and the metre was declared to be equal to ten millionth part of the quadrant of the meridian—which is a fixed and un-

alterable quantity in nature. The quadrant of the meridian was by this measurement found to be 5,130,740 toises, or 10,936,578 English yards: the French metre, or the ten millionth part of this quantity, would accordingly be 1,093,578 yards, or 39.37 inches, nearly. This method of obtaining a standard of measure is not, perhaps, so good as that which consists in observing the length of the pendulum, which, in a certain latitude, beats seconds of mean time. For the length of this pendulum is ultimately ascertained by a reference to the equable motion of the earth upon her axis, and is, therefore, ascertainable without the aid and use of any linear measure whatever; whereas, in the very act of determining the French standard, or the quadrant of the meridian, some linear measure already in use must be employed; and thus the very basis of their new system is expressed in terms of that in the place of which it is substituted.

The importance of possessing the true length of a degree of the meridian, is not confined to investigations having for their object the determination of the figure of the earth. Upon the simple fact of the length of a degree, seemed to depend the overthrow or establishment of the theory of Universal Gravitation. The particulars connected with the discovery of a principle productive of such various effects in nature, is not the less interesting in that it illustrates the secret dependency of parts of science apparently the most distinct, and the assistance which each in its place is calculated to afford to the rest.

The corner-stone of the whole system of Universal Gravitation is, that the force which causes a heavy body to descend to the surface of the earth, is the same that retains the moon in her orbit, and makes her deflect from a straight line, or bend towards the earth. All that was requisite to establish the identity of the forces by which these two effects were produced, was to prove, that the quantity of effect produced in a certain time upon the moon in thus deflecting from a straight line, (taking into consideration the law by which the force varied, and the distance of the moon,) was in due proportion to the effect produced by the force of gravity, in the same time, upon a falling body at the surface of the earth. It is evident, therefore, that the determination of this question depended upon, and would in

its solution be affected by, the distance of the moon from the earth. This distance being expressed only in a number of radii of the earth (about 60), it was necessary to ascertain the length of the earth's radius. This could only be done by means of the proportion which the radius of a circle always bears to the circumference; and the length of the circumference being 360 times that of a degree, the whole matter at last resolved itself into the geodesical operation of accurately measuring a degree upon the earth's surface. The only measure which in 1666, the time of Newton's first taking up the subject, was in existence, was that of Norwood's: this exceeded the true length of a degree by more than 1000 yards; and as this error would be greatly multiplied in each step of the process, it is not surprising that Newton, whether he used this measure, or the still more incorrect one of 60 miles to a degree, could not reconcile the two phenomena of the falling stone and the revolving moon, so as to refer both to the same cause—namely, the attractive force of the earth. The consequence of this error in the then received length of a degree was, that for many years Newton laid aside his theory of universal gravitation. But in 1670, the measurement of an arc of the meridian, by Picard, took place; by mere accident the length of a degree, in latitude $49\frac{1}{2}$, was then ascertained to within 35 yards of what is now considered the true length. This new measure brought Newton back to his favourite hypothesis. He then satisfactorily proved, that the force of gravity, and that force by which the moon is retained in her orbit, are one and the same. It is related, that towards the end of the calculation, and when he perceived its probable successful issue, he became so much agitated, as to be obliged to request a friend to assist him in com-

pleting it. Thus, by the aid of the true length of a degree, was finally established the grand theory of Universal Gravitation.

CHAPTER XI.

Books.

THE subjects embraced in the foregoing treatise, are dispersed throughout a great number of different books, and are to be met with only in detached parts.

The proofs of the spherical figure of the earth, and the methods of finding the latitudes and longitudes of places, will be found in every Treatise of Astronomy; we shall, therefore, only refer to that part of Malte-Brun's work, which is devoted to Mathematical Geography; to the Nautical Almanack; Woodhouse's Astronomy, vol. i. chapters 1, 5, 42 and 43; Brinkley's Elements of Astronomy, chapters 1, 3, 16 and 17; Playfair's Outlines of Natural Philosophy, vol. ii. part 1, chapters 1 and 4; and, as a popular work, to Bonnycastle's Astronomy, letters 2, 9 and 10.

For fuller information, with respect to the true figure of the earth, and the lengths of pendulums vibrating seconds in different latitudes, and measurement and lengths of degrees, we may refer to Malte-Brun; Brinkley, chap. 17; Playfair, chap. 3, of part 1, and chap. 6, of part 2; Bonnycastle, letters 15 and 16; Newton's Principia, book 3, props. 18, 19 and 20; Maclaurin's Account of Sir I. Newton's Discoveries, book 4, chap. 6; Pemberton's View of Sir I. Newton's Philosophy, book 2, chap. 6; Rees' Cyclopædia, articles, 'Earth,' and 'Degree;' various Papers in the Philosophical Transactions on the Measurement of Degrees, and on Experiments upon the Pendulum; Clairaut Figure de la Terre; Quarterly Journal of Science, for March 1827, p. 177.

LLOYD, H. J.

PHYSICAL GEOGRAPHY.

PHYSICAL or *natural* geography might, if we regarded merely the strict meaning of the words, be limited to signify no more than a description of the principal features of the earth's surface; but it is usual, in treatises upon this branch of geography, to touch also upon the subject of climate and temperature,—to show how these, together with other natural causes, affect the condition of the human race—and to advert, in a general manner, to the animals and productions of the globe.

Geographical terms explained.

In looking over a map of the world, it is seen at once that the surface consists of various spaces of *land*, surrounded by an extensive field of water called the *sea* or *ocean*. Of these spaces of land, two are of vast extent, and on this account are termed *continents**, (derived from a Latin word signifying, *holding together* or *connexion*). The larger of these continents includes the three divisions of Europe, Asia, and Africa, and is distinguished by the title of the *old continent*, from its having, till the discovery of America, by Columbus in the year 1492, been the only one with the existence of which Europeans were acquainted. The other, which includes North and South America, is named the *new continent*. The smaller portions of land which are scattered over the ocean are denominated *islands*. A

* New Holland, by some geographers, is regarded as a third continent; but if we consider how much smaller it is than either of the two vast tracts above-mentioned, it will appear correct rather to assign it the first station among the *islands* of the globe. New Holland and the islands around it are, however, not unworthy of being classed as the fifth grand division of the world. English geographers have named them *Australia* (that is, *Southern lands*.)

great many islands lying together are called an *archipelago*.

In many places the land and the ocean run one into the other. When the ocean penetrates into a continent by a narrow passage, and then spreads again into a large expanse, this inland portion of the ocean is usually termed a *sea*. If the extent of such an inland sea be less, or the passage by which it communicates with the main ocean larger, it is called a *gulf* or *bay*. An inland body of water not connected with the ocean or any of its branches, is called a *lake*. A narrow passage of water leading from one sea to another is called a *strait*; a narrow neck of land lying between two seas, and connecting two masses of land greater than itself, is called an *isthmus*. When, on the other hand, a part of a continent runs out into the sea, and is joined to the main land by only a small portion of its circumference, it is named a *peninsula*, (that is, an *almost island*). If the projections of land reach but a little way into the sea, they are called *capes*, *headlands*, or *promontories*.

General View of the Globe as consisting of Land and Sea.

There is, in fact, only one continuous fluid surrounding the land, all the gulfs and inland seas being branches† of this universal ocean; but for the sake of convenience different parts of it have distinct names given to them. The following table, exhibiting the principal seas into which the ocean has been divided, will be clearly understood upon referring to the map of the world on Mercator's projection:—

† The Caspian Sea, as it is generally termed, forms no exception to this remark, because it is in fact only an immense lake.

I.

The great *South-Eastern* basin, the waters of which cover nearly half the globe. It includes

1. The *Antarctic Ocean*, which is comprised within the Antarctic circle, that is, between the parallel of $66^{\circ} 32'$ of southern latitude and the South Pole.

2. The *Southern Ocean*, the boundary of which on one side is the Antarctic circle, on the other a line drawn from Cape Horn to the Cape of Good Hope, thence to Van Diemen's Land, and again by the south of New Zealand to Cape Horn. This line forms the southern boundary of Nos. 3 and 4.

3. The *Indian Ocean*, lying between Africa on the west, and the peninsula of Malaya with the islands of Sumatra, Java, &c., and New Holland, on the east, and bounded by Persia, and Hindustan on the north. The Red Sea, or Arabian Gulf, the Persian Gulf, and the Bay of Bengal are all parts of this ocean.

4. The *Pacific Ocean*, divided by the equator into *North* and *South*, and inclosed between America on the east, and New Holland, the islands of Java and Sumatra, and the continent of Asia, on the west. On the north it terminates at Behring's strait. The seas of China, Japan, Okhotsk, &c. form parts of this ocean.

II.

The *Western* basin, forming a channel between the old and new continents.

1. The *Atlantic Ocean*, commencing in the south from a line drawn from Cape Horn to the Cape of Good Hope, and terminated on the north by the Arctic circle. It is divided into *North* and *South* by the equator, and its branches are the Mediterranean, the North Sea or German Ocean, the Baltic, Baffin's Bay, Hudson's Bay, the Gulf of Mexico and the Caribbean Sea.

2. The *Arctic Ocean*, surrounding the North Pole, and bounded by the Arctic circle and the northern shores of the two continents. The White Sea, the sea of Kara, and the Gulf of Obe are parts of it.

The Ocean is spread over nearly seven-tenths of the globe; but it is remarkable how unequally the land and water are distributed. If we look at a map of the world projected upon the horizon of London, in which map, consequently, London forms the centre of the one hemisphere and the antipodes* to London, the centre of the other; the first hemisphere, it will be seen, contains a very large proportion of the whole of

the land, while the second, if we except New Holland and the extremity of South America, from the twenty-ninth degree of south latitude, consists almost entirely of water. The distribution of water and land is still very unequal, if we compare only the northern and southern hemispheres, that is, the two equal parts into which the globe is divided by the equator. The following calculation will plainly exhibit this fact :

Considering the whole space included in the northern part of the torrid zone, as equal to 1, the proportion of land is

On the same supposition, the proportion of land in the northern temperate zone is

And in the northern icy zone

In the southern part of the torrid zone, the portion of land is

In the southern temperate zone

In the southern icy zone (supposed)

In other words, if the quantity of land in the northern hemisphere be represented by 16, the quantity in the southern will be scarcely equal to 5.

About the middle of the last century it was asserted that a great continent must exist towards the south pole, in order to counterbalance the mass of land in the northern hemisphere; but by the voyages of Cook and others, it has been proved that the high southern latitudes contain only a few islands.—The absence of a continent near the

south pole does not of itself prove that there is less land there than in the north, since it is possible that the land in general may be only rather more depressed in the south, the necessary result of which would be, that the ocean would spread itself more extensively over the surface of the earth in that quarter.

* A small island lying to the south-east of New Zealand, and called Antipodes island, is very nearly the antipodes to London.

On the Figure, &c., of the Continents.

The general direction of the land in the two continents is entirely different. In America, it is from pole to pole; in the old world, it is from south-west to north-east, and, if we keep Africa out of view, it is almost parallel to the equator. The longest straight line that can be drawn on the old continent commences on the western coast of Africa, from about Cape Verd, and extends to Behring's strait in the north-east of Asia. It is about 11,000 miles in length. A similar line, traced along the new continent, passes from the strait of Terra del Fuego, to the northern shore of North America, and is nearly 9000 miles long. In both continents the direction of the large peninsulas is similar, almost all of them running towards the south. This is the case with South America, California, Florida, Alaska, and Greenland in the New World, and in the Old with Scandinavia, Spain, Italy, Greece, Africa, Arabia, Hindustan, Malaya, Cambodia, Corea, and Kamtchatka. The only exceptions to this remark, are the peninsula of Yucatan in Mexico, and that of Jutland in the north-west of Europe. Both of these are directed towards the north; but they consist of plains and alluvial land, whereas the other peninsulas are more or less of a mountainous character. There is a further resemblance between the two continents, from each being divided into two parts by an isthmus*; but in the character of their outlines they differ very much: for while the coast of the Old World (independent of Africa) is broken equally on all sides by gulfs, bays, and inland seas, the New World has a series of openings on its eastern shore only. Of its western side, the only inlet of any magnitude is the gulf of California.

On Mountains.

Mountains are the most considerable elevations of the surface of the earth. They may be divided into two classes: those of which the chains are the most lofty, rugged, and extensive, such as the Andes, the Alps, &c., and those of a less majestic character, which frequently form branches as it were of the first class. The Apennines, which traverse the whole length of Italy, and the Car-

pathian range, which in a great measure surrounds Hungary, are of this second description. All elevations which are either of such an inferior kind, or take place in such a gradual manner as not to come within these two classes, are termed *hills* or *slopes*.

Mountains most commonly are so near to each other, and are disposed in such a manner, as to give the idea of *chains*. A chain may be defined as a series of mountains, the bases of which are continuous; but it is well to observe that the name is sometimes applied to collections of hills without much regard to its strict meaning. Sometimes chains run out from a common centre: those which proceed from the high table-land of central Asia, may be considered as an example; at others the centre mass itself is a lofty chain to which secondary chains are attached: such are the Alps. In some instances there are irregular groups of several chains, among which none can be ranked as the principal: of this the mountains in Asia Minor and Persia are examples. The most remarkable, however, are long connected chains, which, like the Andes†, continue for several thousand miles, nearly in one direction, having on both sides inferior ranges, but sending off hardly any secondary chains. These appear to be of the highest antiquity.

Some mountains are completely insulated, that is, are quite remote from any chain or group. Volcanoes are more particularly of this kind.

The character of mountains would seem to depend upon the sort of rock of which they are composed. Granite, when exposed, forms lofty and rugged elevations; gneiss is much less precipitous, and slate commonly not at all so. In this respect there is a remarkable difference, which Humboldt has noticed, between the Old and New Continents. In the former the highest points of the Alps consist of granite; but in America, granite is not found higher than 11,000 or 12,000 feet above the level of the sea, and the newest flœtz trap or whinstone, which in Europe appears only in low mountains, or at the foot of those of great magnitude, covers the tops of the Andes. Chimborazo and Antisana are crowned with vast walls of porphyry; and basalt, which in our

* The isthmus of Suez is composed of sand; that of Panama or Darien consists of stupendous rocks.

† The name of *Andes* is given only to the chain on the west coast of *South America*; the continuation of that chain in North America has other titles; but they evidently form one grand whole.

continent has not been observed higher than 4300 feet, is on the very summit of Pichincha. Other secondary formations, among which may be mentioned limestone, are also found at greater heights in the New than in the Old world.

With respect to their declivities, it is observed that most of the principal mountains have one of their sides very steep, and the other of a gradual slope. The Alps, for instance, have a much more abrupt descent on the side of Italy than on that of Switzerland; the Pyrenees are steeper towards the south than the north, while the chain of Asturias, which branches westward from the Pyrenees, is just the reverse. Mount Taurus, in the part where it approaches the Mediterranean and the Dardanelles, is abrupt on the south, but in Armenia it has a rapid descent northward. The mountains of Scandinavia are steeper towards the west and north-west, than the south and east; and the Ghauts in Hindustan are in like manner precipitous on the west, and sloping in the opposite direction. With all these chains, therefore, and indeed with most of the chains of the globe, their steepest side is found to be that which approaches most nearly to the sea, and consequently their inclination is most gradual towards the interior of the country in which they are situated.

Mountains in their course commonly make numerous curves and angles; but in most cases the *general direction* of the principal chains appears almost, if not entirely, to correspond with the greatest length of the continents to which they belong. The Andes in South and the Stony Mountains in North America exemplify this remark; as do also the chains which, with little interruption, pass from the north-eastern point of Asia to the south-west coast of Portugal, and to the western side of Africa. The secondary chains, in the same manner, frequently follow the greatest length of the large peninsulas. This is the case with the Apennines in Italy, the Dovrefield in Scandinavia, the Ghauts in Hindustan, &c.

In order to obtain a connected view of the loftiest and most extensive system of mountains upon the globe, we must suppose ourselves placed in New Holland with our face turned towards the north; America will then be on the right, Asia and Africa on the left. From Cape Horn to Behring's strait

along the western coast of America, there is an almost uninterrupted range of the highest mountains; from Behring's strait again succeeds an enormous line passing in a south-westerly direction through Asia, leaving China and Hindustan to the south, somewhat interrupted as it approaches Africa, but still to be looked upon as continuing its course in the mountains of Persia and Arabia Felix. From Cape Gardafui in Africa to the Cape of Good Hope, there appears to be a chain which completes the view. The series of mountains which we have thus followed, is in the form of an immense irregular curve, which comprises within it, the Pacific and Indian Oceans, with their innumerable islands, besides a portion of Asia, including China, the Birman dominions, and the Indian peninsula. It presents a steep face towards these oceans, while, on the other side, the land very generally slopes towards the Atlantic and Arctic Oceans.

The following is a table of the height of some of the principal mountains of the globe, reckoning from the level of the sea. The elevations of those in Asia and Africa are far from having been ascertained with accuracy. Some recent measurements make the highest summits of the Himalayan range as much as 28,000 feet; but, though these calculations seem very doubtful, it is not unlikely they are at least 25,000 feet high.

Europe.

	Feet.
Mont Blanc †	15,668
Mont Rosa	15,527
Ortler Spitze in the Tyrol	15,430
Aiguille d'Argenture	13,389
Eiger	13,170
Jungfrauhorn	The Alps 13,730
Shreckhorn	13,310
Wetterhorn	12,500
Pass of Great St. Bernard	7,968
Ditto of Mont Cenis	6,778
Ditto of the Simplon	6,580
Nethou †	11,427
Perdu	Pyrenees 11,275
Canigou	9,145
Monte Corno † (Apennines)	9,523
Lomnitz † (Carpathian)	7,962
Sneehaetta † (Dovrefield in Norway)	8,122
Mulhacen † (Sierra Nevada of Grenada in Spain)	11,678
Mont Mezin † (Cevennes in the south-east of France)	6,567
Puy de Sancy † (Mountains of Auvergne in France)	6,215
Etna * in Sicily	10,870
Vesuvius * near Naples	3,932

Asia.

		Feet.
Dhawalagiri	} Himalaya	28,077
Jewahir		25,747
Mowna Roa (Sandwich Is.)		15,988
Ophir (Sumatra)		13,840
Egmont (New Zealand)		11,430
Italitzkoi (Altaian chain)		10,735
Ararat (Armenia)		9,600
Olympus (Anatolia)		6,500
Awatsha* (Kamtchatka)		9,600
Lebanon (Palestine)		9,600

Africa.

Geesh	} Abyssinia	15,000
Amid Amid		13,000
Lamalmou		11,200
Chain of Atlas†		11,980
Peak of Teneriffe*		12,180

America.

Chimborazo†	} Andes	21,425
Cayambe		19,633
Antisana*		19,136
Cotopaxi*		18,867
Yliniza		17,376
Tolima		18,324
Cotacache		16,436
Pichincha*		15,931
Farm of Antisana (inhabited)		13,437
City of Quito		9,542
Popocatepetl*	} Mexico	17,720
Iztaccihuatl		15,705
Coffer of Perote		13,275
Lake of Toluca		12,195
Silla de Caraccas (Venezuela)		8,633
Duida (Mountains of Parime)		8,314
Itacolumi (Brazil)		5,756
Mount Washington† (Alleghanies)		6,650
Blue Mountains (Jamaica)		7,278
Mount St. Elias		17,863
Mount Fairweather		14,736

(NOTE) Those marked * are volcanoes. And † are the highest points of the range to which they belong.

On Volcanoes.

The term *Volcano* (derived from VULCANUS, the name which the Romans gave to their imaginary god of fire) is applied to those mountains which send forth from their summits or sides, flame, smoke, ashes, and streams of melted matter called lava. Upon ascending to the top of a mountain of this kind, there is found to be an immense and deep hollow, which is denominated the *crater* or *cup*. From most of the volcanoes which are not extinct, there is a smoke more or less frequently arising; but the *eruptions*, which are discharges of stones, ashes, lava, &c., accompanied with lofty columns of fire, violent explosions and concussions of the earth, happen at irregular and sometimes very long intervals. It seems to be a very general rule that the

greater the mass and the elevation of the mountain, the less frequent and more tremendous are the eruptions. Stromboli, the small volcano on one of the Lipari islands, is almost always burning; Vesuvius has more frequent eruptions than Etna; while the immense summits of the Andes, Cotopaxi, and Tungurahua have an eruption hardly once in a century. The volcanoes of America, besides the common lava and rocks, &c., cast out scorified clay, carbon, sulphur, and water*, accompanied, in some instances, by fishes.

The eruption the most astonishing, perhaps, of any upon record is that which, in April 1815, issued from the Tomboro mountain in Sumbawa, one of the islands of the Indian Archipelago (see Notes to chap. i. of *Raffles' History of Java*); and we mention it, in order to give an idea of the violence which sometimes characterises volcanic agency. The tremulous motions which the ground underwent, during this eruption, were felt throughout a circular space of nearly 2000 miles in diameter, and the report of the explosions was heard over an equally extensive area. Within its more immediate range, embracing a space of 300 miles around it, it excited the greatest alarm. On Java, at the distance of 300 miles, the sky was overcast at mid-day with clouds of ashes, the showers of which covered every thing to the depth of several inches; and explosions were heard, at intervals, like the report of artillery or the noise of distant thunder. On Sumbawa itself thousands of individuals were destroyed by the fury of the eruption.

What may be termed *mud volcanoes*, from their having eruptions of mud only, are another curious phenomenon. One of these, which is situated towards the middle of the island of Java, in a plain abounding with salt springs, is thus described in the 9th volume of the *Batavian Transactions*: "On approaching it from a distance, it is first discovered by a large volume of smoke, rising and disappearing at intervals of a few seconds, resembling the vapours arising from a violent surf: a dull noise is heard, like that of distant thunder. Having advanced so near, that the vision was no longer impeded by the smoke, a large hemispherical mass was observed, consisting of black earth mixed with water, about 16 feet in diameter, rising to the height of

* Etna has been known to eject Water.

20 or 30 feet in a perfectly regular manner, and, as it were, pushed up by a force beneath—which suddenly exploded with a dull noise, and scattered about a volume of black mud in every direction. After an interval of two or three, or sometimes four or five, seconds, the hemispherical body of mud or earth rose and exploded again. In the same manner this volcanic ebullition goes on without interruption. The spot where it occurs is nearly circular and perfectly level; it is covered only with the earthy particles, impregnated with salt water, which are thrown up from below: the circumference may be estimated at about half a mile. A strong, pungent, sulphureous smell is perceived on standing near the explosion, and the mud recently thrown up is warmer than the surrounding atmosphere. During the rainy season these explosions are more violent."

The mountain of *Maccaluba* in Sicily, and some hills at the town of Taman in the Crimea, are also distinguished by eruptions of mud.

It is remarkable, that in the Old Continent, the principal chains of mountains contain no volcanoes, and that islands, and the extremities of peninsulas, are alone the seats of these convulsions; while in the New World, the immense range which runs along the shore of the Pacific Ocean possesses more volcanoes than are to be met with in the whole of the Old Continent and its adjacent islands. Professor Jameson has given the following estimate of the number of volcanoes:—

Continent of Europe	1*
Islands of ditto	12
Continent of Asia	8†
Islands of ditto	58
Continent of America	97
Islands of ditto	19

No volcano has yet been discovered on the continent of Africa, but most of its groups of islands are distinguished by them.

A line drawn round the Great Pacific Ocean, so as to include the long range of mountains on the west of America, the Asiatic peninsula of Kamtchatka, and the islands of Sumatra and Java, will have within it, by far the grandest and most extensive *volcanic system* on the globe. From Terra del Fuego, (*the land of fire*,) to the peninsula of Alaska,

a complete series of volcanoes may be traced. The Aleutian islands, which stretch from that peninsula to the opposite peninsula of Kamtchatka, possess several. On Kamtchatka, there are some of great violence. The islands of Japan and Formosa have several, and beginning with Sumatra and Java, they are scattered all over that immense Archipelago which forms so remarkable a feature of the Pacific Ocean.

In the Indian Ocean, the Islands of St. Paul, Amsterdam, and Bourbon, have volcanoes in action. The most formidable volcanoes of the Mediterranean are Etna in Sicily, and Vesuvius upon the coast of Naples. Between these two mountains are the Lipari islands, all of volcanic character. The Atlantic Ocean contains several groups of this kind; Iceland has suffered frequently from the terrific eruptions of its volcanoes; the Azores and the Canaries, and some of the West India islands, also experience the effects of subterranean fire.

In some places, parts of the land which are covered by the waters of the ocean are the seats of volcanoes; and it has sometimes happened, that new islands have been formed during *submarine* eruptions. A recent instance of this kind occurred in 1811, in the neighbourhood of St. Michael, one of the Azores, the small group which lies about 800 miles to the west of Portugal. This new island has since disappeared. It is probable, that some clusters of islands (among which are the Azores, just mentioned, and the Lipari islands north of Sicily) owe their origin to the breaking out of submarine volcanoes.

Several mountains bear evident marks of having at some very distant period been the outlets of fires; and on this account, they are called *extinct* volcanoes.

On Valleys and Plains.

Valleys are the spaces lying between opposite ridges of mountains or of hills, and their lowest part is commonly the bed of some torrent or river, which originates in the higher grounds. Those between high mountains are in general narrow and long, resembling large clefts or fissures. In some of these valleys, among the Alps and Pyrenees, it has been observed, that the nooks or angles on each side correspond with such exactness to projections on the opposite side, that if it were possible

* Vesuvius.

† On the peninsula of Kamtchatka.

to exert a force sufficient to bring their sides together, they would fit into each other so closely, that no trace of the opening would remain. Such valleys as these would seem to have been formed by some convulsion of nature. The narrow openings which are the entrance to the high valleys, are called *passes* or *defiles*, and these are often of the most gloomy and terrific aspect. Valleys, which are upon a lower level than the class just mentioned, are wider and more soft in their features, and gradually lose themselves in the plains. *Plains* are likewise of two kinds. Those which are extensive, but very elevated, come under the denomination of *table land*. There are several plains of this sort; but the most remarkable are those among the Andes*, those of Mexico, and the immense plains in central Asia, to the north and north-east of Hindustan. The great Himalayan and Altaian chains form the ramparts, as it were, of this extensive and desolate table-land, a large proportion of which is the desert of Gobi† or Shamo. The *low plains*, from the nature of their soil, seem formerly to have been covered by the sea. The large plain, to the south of the Baltic, is one out of several instances of this character.

On Islands.

Large islands exhibit, on a smaller scale, the same appearances as the continents: upon them, therefore, it is unnecessary to make any observations, but with respect to smaller islands, the circumstance of their commonly being in groups or chains, deserves attention. Some are banks of sand, just raised above the surface of the water. Many islands, especially those in the South Sea, owe their origin to the marine insects which produce the coral. Some groups, as has already been observed, appear to have been raised up by the action of submarine volcanoes. Since the bed of the ocean possesses as much variety of surface as the land, there is no doubt that groups or chains of islands very near to each other, and which have not been raised up by such processes as those just alluded to, are only the different summits of an extensive submarine system of mountains; and when these collections of islands lie

close to mountains on shore, they may be considered as a continuation of the latter. The Aleutian isles, which run in a curve south of Behring's strait, connect in this manner the mountains of the New with those of the Old World. In some cases, where a chain of islands extends from one part of the shore of a main land to another, it would appear as if, at a remote period, the sea had overwhelmed a portion of the main land, leaving those spaces uncovered which now form the islands. This seems still more probable if the water on the land side of the chain be not very deep, or if the islands are of a lofty and mountainous character. It has been supposed that, among others, the West India islands and the Archipelago between New Holland and the opposite coast of Asia, were rendered insular by an incursion of the ocean having detached them from the continents to which (if this supposition be just) they formerly belonged.

On Springs and Rivers.

The origin of the numerous springs that break forth from beneath the earth's surface cannot be referred to one exclusive cause. The internal reservoirs by which they are supplied are, in many cases, derived from the water which the earth absorbs from rains and melted snow; from these reservoirs, wherever there is uneven or mountainous ground, the water flows out by minute fissures in the sides of the hills. But when we see springs rising up in plains, it is evident that they must have *ascended*, that is, travelled in a direction *contrary* to that produced by the force of gravity, in order to reach the surface. This, no doubt, is sometimes to be attributed to water flowing under ground from distant elevations, and to the natural tendency of a liquid to find its level. But the rising up of springs, in plains, cannot always be accounted for in this manner; and it has, therefore, been supposed, that the earth contains capillary tubes, the effect of which, in attracting liquids upwards, is explained in Chapter VIII., of the treatise upon Hydrostatics. It is also evident that such springs as suffer no diminution even from the longest continued dry weather, must be derived from a source quite independent of rains, and other external means of supply. They must, therefore, proceed from some vast body of water within the earth; and it has,

* The plains of Quito are 12,000 feet above the level of the sea.

† This word, which is usually but incorrectly written *Kobi* or *Cobi*, signifies a *naked desert*.

with apparent reason, been concluded, that many springs arise from the ocean filtering through the pores of the earth, the salt particles being lost in the passage.

Springs, which have their waters combined with mineral substances, and are, from that circumstance, called *mineral*, are very numerous, and of various kinds. *Warm* and *hot* springs are also common, especially in volcanic countries, where they are sometimes distinguished by violent ebullitions. Iceland is noted for these curious phenomena: its celebrated boiling fountain, the great *Geyser*, frequently throws out its contents to the height of more than a hundred feet, sometimes to twice that elevation.

Rivers are to be traced to springs, or to the gradual meltings of the ice and snow which perpetually cover the summits of all the most elevated ranges of mountains upon the globe. The union of various springs, or of these meltings, forms rivulets: these last follow the declivity of the ground, and commonly fall, at different stages, into one great channel, called a river, which, at last, discharges its waters into the sea, or some great inland lake. The declivities along which descend the various streams that flow into one particular river are called its *basin*, a term, therefore, which includes the whole extent of country from which the waters of the river are drawn. As mountainous regions abound in springs, we find that most rivers, more especially those of the first class, commence from a chain of mountains: each side of a chain also has its springs, and the rivers which originate on one side flow in the opposite direction to those which rise on the other. As it is the property of water to follow the most rapid descent that comes in its way, the courses of streams naturally point out the various declivities of the earth's surface, and the line from which large rivers flow in contrary directions will generally mark out the most elevated parts of the earth. In European Russia, where the rivers are very extensive, there is, however, a singular exception to this rule, the line which separates the sources of those rivers being very little above the level of the Baltic or of the Black sea. It has been observed by some writers, that the extent of a river is in proportion to the height of the range of mountains from which it descends. This is,

in a certain degree, true, because the greater the bulk of the mountains, the more numerous the springs and torrents which they furnish; but the relation between the extent of a river and the surface of its basin is much closer and more invariable. Even this is not sufficiently comprehensive, for it is evident that the size of a river depends upon three circumstances—the surface of its basin—the abundance or otherwise of that surface in springs—and the degree of humidity possessed by the climate of the region from which it draws its supplies. As many springs, however, are formed by the rains, the second of these circumstances will, in some measure, vary with the last. By an attention to these remarks, the causes of the great size of the South American rivers will be apparent. The peculiar position of the Andes with respect to the plain of that continent,—the fact that by very far the largest proportion of its running waters are drained off in one general direction (towards the Atlantic)—the multiplicity of streams that intersect the country,—and the humidity of the climate, all contribute to that result. The Andes being placed so near the coast of the Pacific, the rivers which flow from them into that ocean are small; while those which flow on the other side, having such an immense space to traverse, are swelled into a most majestic volume before they reach the Atlantic. The physical circumstances of the old continent are unfavourable to the accumulation of such vast bodies of water as the rivers of South America. Europe is not of sufficient extent; Africa is oppressed by a scorching climate, and abounds in sandy deserts; in Asia the atmosphere generally is not so moist, while the more central position for the most part of the great mountainous range of that continent, and the existence of capacious inland lakes*, which are the final receptacles of the streams that fall into them, are the causes why the waters are more equally drained off in different directions than in the New World.

When water, by following a descent, has once received an impulse, the pressure of the particles behind upon those before will be sufficient to keep the stream in motion, even when there is no longer a declivity in the ground. The only effect is, that in passing along a

* The Caspian Sea and Lake Aral.

level, the course of the stream becomes gradually slower, an effect which may be perceived, more or less, in all running waters that originate in mountainous or hilly tracts, and afterwards traverse the plains. The declivity of many great rivers is much less than might at first be supposed. The Marañon or Amazons has a descent of only $10\frac{1}{4}$ feet in 200 leagues of its course, that is, $\frac{1}{27}$ th part of an inch for every 1000 feet of that distance. The Loire, in France, between Pouilly and Briare, falls one foot in 7,500, but between Briare and Orleans, only one foot in 13,596. Even the rapid Rhine has not a descent of more than four feet in a mile, between Schaffhausen and Strasburg, and of two feet between the latter place and Schenckenschantz. When rivers proceed through mountainous and rugged country, they frequently fall over precipices and form *cataracts*, in some cases several hundred feet in depth. The most celebrated falls in the world are those of the Niagara, in North America.

In the tropical regions most of the rivers are subject to periodical overflowings of their banks, in consequence of the rains which annually fall in such abundance in those countries during the wet season. The overflow of the Nile was considered by the ancients, who were ignorant of its cause, as one of the greatest mysteries of nature, because in Egypt, where the overflow takes place, no rain ever falls. The apparent mystery is easily explained, by the circumstance of the rains descending upon the mountains in the interior of Africa where the Nile rises. The consequent accumulation of the waters among the high grounds gradually swells the river along its whole extent, and in about two months from the commencement of the rains, occasions those yearly inundations, without which, Egypt would be no better than a desert.

The disappearance of some rivers for a certain distance under ground is accounted for with equal facility. When a river is impeded in its course by a bank of solid rock, and finds beneath it a bed of a softer soil, the waters wear away the latter, and thus make for themselves a subterraneous passage. In this way are explained the *sinking of the Rhone*, between Seyssel, and l'Ecluse, and the formation, in Virginia, of the magnificent rock bridge which overhangs the course of the Cedar creek. In

Spain the phenomenon exhibited by the Guadiana, which has its waters dispersed in sandy and marshy grounds, whence they afterwards emerge in greater abundance, is to be referred to the absorbing power of the soil.

Rivers, in their junction with the sea, present several appearances worthy of notice. The opposition which takes place between the tide and their own currents occasions, in many instances, the collection at their mouths of banks of sand or mud, called *bars*, on account of the obstruction which they offer to navigation. Some streams rush with such force into the sea, that it is possible, for some distance, to distinguish their waters from those of the sea. The shock arising from the collision of the current of the majestic Amazons with the tide of the Atlantic is of the most tremendous description. Many of the largest rivers mingle with the sea by means of a single outlet, while others, for instance the Nile, the Ganges, the Volga, the Rhine, and the Orinoco, before their termination, divide into several branches*. This circumstance will depend upon the nature of the soil of the country through which a river runs; but it also frequently results from the velocity of the stream being so much diminished in its latter stage, that even a slight obstacle in the ground has power to change its course, and a number of channels are thus produced. Another cause may be assigned for the division into branches of those rivers, which, in tropical countries, periodically inundate the plains; the superfluous waters which, at those periods, spread over the country, find various outlets, which are afterwards rendered permanent by the deepening of the channels by each successive flood. In some of the sandy plains of the torrid zone the rivers divide into branches, and, from the nature of the soil and the heat of the climate, they are absorbed and evaporated, and thus never reach the sea.

On Lakes.

Lakes may be classed into *four* distinct kinds. The *first class* includes those which have no outlet, and which do not receive any running water. They are usually very small; some appear to be the craters of extinct volcanoes filled

* The triangular space formed by a river pouring itself into the sea by various mouths, is called a *Delta*, from its resemblance to the shape of the fourth letter (Δ) of the Greek alphabet.

with water. The *second class* are those which have an outlet, but which receive no running water. They have been formed by springs flowing into some large hollow : upon the water rising up to the top of the hollow, it would, of course, run over the lowest part of the edge, and thus find an outlet, and these outlets are, in some cases, the beginnings of very large rivers. As these lakes receive no stream, they must necessarily, in most cases, be in elevated situations. There is one of this kind on Monte Rotondo in Corsica, which is 9000 feet above the level of the sea.

The *third class*, which embraces all those which both receive and discharge streams of water, is much more numerous than any. Though they are the receptacles of many streams from the neighbouring country, they usually have each but one outlet, which often takes its name from the principal river that runs into the lake. The largest lakes of this class are the immense bodies of water in North America, between Canada and the United States. There are five, (Superior, Michigan, Huron, Erie, and Ontario,) almost like seas in extent, connected together, and their purity is maintained by means of the continual flow of water which is kept up from one to another. Their final outlet to the Atlantic Ocean is the great river St. Laurence. Lake Baikal, in Asiatic Russia, is also remarkable for its size; it sends forth a large stream which joins the Yenisei.

The *fourth class* of lakes comprises a very small number, but they are the most singular in their character of all. They are those which receive streams of water and often great rivers, but have no visible outlet whatever. The most celebrated are the Caspian Sea and Lake Aral, both situated in the west of Asia. The Caspian is between 600 and 700 miles long, and, in one part, between 300 and 400 miles in width; it receives some very large rivers, the chief of which are the Volga, the Ural or Yaik, and the Kur; yet, notwithstanding the plentiful supply of water which is constantly being poured into it, it not only exhibits no increase, but there is strong reason to believe, from the appearances round its shores, that its surface is now much lower than it was at a former period*. Many con-

jectures have been offered to account for this apparent anomaly; but, after all, the process of evaporation seems quite sufficient to explain it, especially when we consider the extensiveness of the surface which this inland sea (as it is termed) presents, to be acted upon by the atmosphere. Lake Aral is much smaller than the Caspian, but possesses the same peculiarities, and, from the character of the isthmus which separates them, it is supposed that they formerly composed one body of water. They are both *salt* lakes, and are distinguished by marine productions; from these circumstances it has been conjectured that they must, at a very remote period, have been connected with the Black Sea. If such a connection ever existed, the separation may have been occasioned by an accumulation of alluvial soil, brought down by the rivers Don and Volga.

The phenomena presented by some lakes are of a very curious kind. Several of these bodies of water are *periodical* in their appearance. In tropical countries, owing to the violent rains and the overflowing of the rivers, spaces of several hundred miles are often covered with water. South America has large lakes which are annually formed in this manner, and are again dried up by the powerful evaporation of an equatorial climate. Some lakes there are which periodically appear and disappear, owing (it is thought) to their invisible connexion with some subterranean reservoir, by the alternate increase and diminution of which they are necessarily influenced. Lake Cirknitz in Illyria is of this description. The motions and agitations which certain of these bodies of water experience are more difficult to explain. Some of them appear agitated by the escape of subterraneous gases, or by winds that blow in some cavern with which they communicate. Loch Lomond, in Scotland, and Lake Wetter, in Sweden, are often violently agitated during the calmest weather. The floating islands which exist in several lakes, seem to have been formed by the water first undermining and then detaching from the bank very light earth of the nature of peat; sometimes they are merely reeds and roots of trees woven together. Those of the lake of

* By means of observations made with the barometer upon the coasts of the several seas, the surface

of the Caspian was ascertained to be 306 feet below that of the Baltic, and nearly 345 below that of the Black Sea.

Gerdau, in Prussia, are said to yield pasturage for one hundred head of cattle; and in the lake of Kolk, in Osnabruck, there is one which is covered with elm trees.

On the Changes which take place in the Earth's Surface.—Action of Running Waters.—Breaking down of Coasts.—Encroachment of Sands.—Formation of New Islands.—Volcanoes.—Earthquakes.

FROM the quiet and regular succession of natural events to which we are accustomed, and the repugnance we feel to the idea that it is possible for the course of nature to suffer interruption, we might, without due investigation, almost persuade ourselves that the physical features and condition of the globe possess an unchangeable character. So far, however, is this from being the case, that there is no country wherein traces are not discoverable of the great changes and violent revolutions of which the earth has formerly been the theatre. The confusion often exhibited in the position of the different strata or layers of which the crust of the earth is composed, the frequent discovery of the remains of animals and vegetables deeply buried in the soil, and many other appearances, testify that the surface of the globe has undergone convulsions, to the production of which none of the natural agents with which we are acquainted can be regarded as adequate; unless they once acted in a method, and with an extent of violence, of which it is impossible for us, by reference to what now exists, to form a conception. "The lowest and most level parts of the earth exhibit nothing, even when penetrated to a very great depth, but horizontal strata, composed of substances more or less varied, and containing almost all of them innumerable *marine productions*. Similar strata, with the same kind of productions, compose the lesser hills to a considerable height. Sometimes the shells are so numerous as to constitute of themselves the entire mass of the rock; they rise to elevations superior to the level of every part of the ocean, and are found in places where no sea could have carried them at the present day, under any circumstances; *

they are not only enveloped in loose sand, but are often inclosed in the hardest rocks. Every part of the earth, every continent, every island of any extent, exhibits the same phenomenon." (*Cuvier's Essay on the Theory of the Earth.*) The perfect state in which these shells are generally found, and the regularity, thickness, and extent of the beds that contain them, prove that they could not have been deposited in their places by any temporary invasion of the sea, but that the water must have remained there long enough in a state of tranquillity, to have allowed them gradually to deposit themselves. Some of the strata of marine formation are much more *recent* than others; while in the midst of even the oldest strata of this kind, other strata appear full of animal or vegetable remains of *land* or *freshwater* productions. On these accounts, it would seem as if the land, now inhabited by man, had experienced various successive irruptions and retreats of the sea. There are also appearances which lead to the conclusion that the catastrophes which have occasioned these changes have been sudden and violent. To numberless living beings, they were the messengers of destruction, and of many, the very races have been utterly extinguished. Cuvier, the celebrated French geologist and natural historian, from an observation of the *fossil bones* of more than one hundred and fifty quadrupeds, has determined that upwards of ninety of these animals were of kinds *unknown* to naturalists. There can be no doubt that the revolutions in which these animals were destroyed, occasioned great changes of climate in many parts of the earth, and that in some instances, at any rate, the change took place very rapidly. Fossil plants, and animals of similar kinds to some which still exist in warm regions, have been found in countries where the cold is very much beyond what such kinds are capable of sustaining; and in the arctic zone, the carcasses of large quadrupeds have been discovered enveloped in the ice with their skin, hair, and flesh, still remaining, so that the alteration in the climate must have occurred with such suddenness, as to prevent their bodies from being decomposed by putrefaction.

Such are some of the traces that bear witness to the revolutions which the surface of the globe has undergone. These wonderful and destructive events,

* *Fossil shells* have been found on the summits of the Pyrenees; and among the Andes as much as 13 and 14,000 feet above the level of the sea.

of the immediate causes of which nothing can be declared with certainty, must have long ceased; but the earth has since experienced, and is still experiencing, changes of a very perceptible kind, which we shall now proceed to notice.

Of the several agents which contribute to these changes, water has the widest sphere of activity. In all abrupt and precipitous mountains, fragments of earth and rock are continually falling down from the higher parts, owing to the slow, but effectual action of rains, storms, &c.; and these become rounded by rolling upon each other. These fragments collect upon the sides and at the foot of the mountains, and, on some occasions, when undermined by rivulets*, have been known to slip down in immense masses, and by stopping up the course of rivers, create great devastation. But, without any such extraordinary occurrences as these, the streams that descend along the flanks of elevated grounds carry along with them some portion of the materials of their respective slopes, especially when swelled into violence by rains or the melting of snows; and such as come from mountains sweep down with them even some of the fragments of rock that have been collected in the high valleys. In proportion, however, as these streams reach the more level country, and their channels become more expanded, they deposit the fragments and stones, till at last their waters convey along only particles of mud of the minutest kind. If, therefore, these waters do not run too rapidly into the sea, or the particles in question do not previously settle in some lake through which the rivers pass, the mud is deposited at the sides of their mouths, forming low grounds, by which the shores are prolonged and encroach upon the sea; and when the

waves, by casting up sand upon them, assist in their increase, whole provinces are created, capable, from their rich soil, of yielding, in the highest degree, to the support of man, and of being made the seats of wealth and civilization.

It has been concluded, with reason, that the greater part of Lower Egypt owes its formation to the alluvial matter brought down by the Nile, aided by the sand cast up by the sea. M. Dolomieu has endeavoured to show that the tongue of land on which Alexandria was built, (331 years before Christ,) did not exist in the days of Homer; (about 900 B. C.) and that the lake Mareotis was, at the latter period, a large gulf of the sea. In the time of Strabo, the geographer, who lived about the commencement of the Christian æra, this gulf had been inclosed by land, and is described as a *lake* of six leagues in length. More certainty exists as to the changes that have occurred since that period. The sand thrown up by the sea and wind has formed, near the site of the ancient town, a narrow tongue, on which the modern Alexandria stands. It has blocked up the nearest mouth of the Nile, and reduced the lake Mareotis almost to nothing; while the rest of the shore has been very much extended by the continual deposition of alluvial matter. In the time of the ancients, the Canopian and Pelusian were the principal mouths of the Nile,† and the coast ran in a straight line from the one to the other. The water now passes out chiefly through the Bolbitian and Phatnitic mouths; and round them the greatest depositions have taken place, to which the coast is indebted for its swelling outline. The cities of Rosetta and Darnietta, which were built upon these mouths close to the sea, less than 1000 years back, are now six miles distant from it. At the same time that the sediment of the Nile occasions an extension of the land, both the bed of the river and the country, which is periodically covered by the overflow of the waters, are, from the same cause, gradually being raised to a greater elevation. As a proof of this elevation of the soil, it is stated that at Cairo, before the rise of the river is

* Large masses of rock have, however, been known to detach themselves, and roll down from mountains without any apparent cause.

In Mr. Bakewell's Travels, vol. I., p. 195—202, there is an interesting description of the fall of a part of Mont Grenier, in Savoy, which took place in 1243. The ruins spread over an extent of nine square miles, and entirely buried five parishes, and the town and church of St. André. Some of the small hills or rocks, of which the ruins consist, are at the distance of three and four miles from the mountains from which they were separated. This catastrophe, Mr. Bakewell remarks, must have been caused by the gradual decay of the soft strata, of which the lower part of the mountain consists; whereby the mass of limestone above was undermined, and becoming detached, fell with destructive violence into the plain. There are appearances about Mont Grenier which threaten a renewal of the catastrophe of 1243.

† The Canopian or westernmost mouth, which used to discharge itself into the sea not far from the site of Aboukir, is now lost in the lake of Etikoo; the Pelusian, the easternmost mouth of the Nile still exists, but in a very insignificant state, flowing through the lake Menzaleh.

deemed sufficient for the purpose of irrigation, its height must exceed by $3\frac{1}{2}$ feet that which was requisite ten centuries ago. According to this statement, the ground must have been raised at the rate of nearly $4\frac{1}{4}$ inches in a century. The ancient monuments of the land all have their bases, more or less, covered by the mud which has been, for ages, accumulating around them.

The delta of the Rhone undergoes a similar augmentation, and it would appear that the arms of that river have, in the course of 1800 years, become longer by three leagues; and that many places which were once situated on the brink of the sea, or of large pools, are now several miles distant from the water. In Holland and Italy, the Rhine and the Po, since they have been banked up by dikes, raise their beds and push forward their mouths into the sea with great rapidity. Many cities which, at periods within the range of history, were flourishing sea-ports, have, by the encroachments on the water, been deprived of their importance. It is with extreme difficulty that the Venetians are able to preserve the *lagunes** by which their city is separated from the main land; and in all probability Venice is destined to experience the fate of Ravenna, which, according to Strabo, stood among lagunes in the time of the Roman emperor Augustus, but is now a league from the shore. M. Cuvier records some curious information which he obtained from M. de Prony, inspector-general of bridges and roads, who was appointed to investigate the remedies that might be applied to the devastations committed by the floods of the Po. This clearly displays some of the surprising changes which the coast of the Adriatic has undergone. At the beginning of the twelfth century, the whole waters of the Po flowed to the south of Ferrara, in the two channels called Po di Volano, and Po di Primaro; an irruption of the river to the north of that city happened not long after, and owing to this new direction of the stream, the two old channels in question had, in less than 100 years, been reduced to the comparative insignificance in which they still remain. Since the construction of the grand embankments of the Po, the formation of New Land has proceeded very rapidly, especially within

the last two centuries. Such indeed has been the increase, that the city of Adria, which there is no doubt was, at a very remote date, seated on the coast of the *Adriatic*, is now more than fifteen miles distant from the nearest part of it. The distance from the same city to the extreme point of the promontory of the alluvial land, deposited round what is now the principal mouth of the Po, is upwards of twenty miles. At the same time that river has so much raised the level of its bottom, that the surface of its waters is now higher than the roofs of the houses in Ferrara; and the Adige and the Po are higher than the whole tract of country lying between them. The high level above the surrounding plain, attained by the Rhine and the Meuse in Holland, since they have been banked up; the additions of land that have been made along the shores of the North Sea, in Holstein, Friesland, Groningen, &c.; and the diminution of the sea of Azof, by the entrance of alluvial matter from the Don, are further instances of the changes which nature is able to produce by the most simple means. The *Yellow Sea* (so named from its waters being coloured by an intermixture of particles of yellow mud) affords a similar example. This sea, which lies between the peninsula of Corea and the eastern coast of China, is exceedingly shallow, as may be seen from the account of Capt. Hall, who navigated it in the year 1816—(*Voyage to Loo-Choo*, &c.) That officer states, that no land could be perceived from the mast-head at the time when his ship was in less than five fathoms water; and, before a sight of land was obtained, even this depth was considerably reduced. The bottom consisted of mud, formed of an impalpable powder, without the least sand or gravel. The fine particles, from which this mud is deposited, are brought down by innumerable streams from China and Tartary.

The alterations perceived to be taking place in many of those lakes which are traversed by rivers, proceed from the same cause as the extensions of alluvial land into the sea which we have just been considering. The matter brought down by rivers easily settles in the still water of lakes, and the necessary result is, that the basins of the latter are gradually undergoing a diminution. This process, carried on for a sufficient length of time, would end in the filling up of the lake, and in its place there would

* These are very extensive sheets of water, but so shallow that they, in no part, exceed six or seven feet in depth.

be a valley intersected, of course, by the same rivers which formerly flowed into the lake. Owing to the very long time required for the purpose, there is no instance known of a lake, of any size, ever having been filled up in this manner; but there are well authenticated cases of their being very sensibly diminished. Lake Erie, one of the vast bodies of water in North America, is rapidly decreasing; in the late survey of the boundaries between the United States and Canada, it was ascertained that Long Point, opposite Big Creek river, on the north side of the lake, had, in the space of three years, increased more than that number of miles in length by the accession of alluvial matter; and this immense basin, the average depth of which is estimated at between thirteen and seventeen fathoms, is every year becoming shallower from the influx of pebbles and earth, and the constant accumulation of reeds and shells. The diminution of the beautiful lake of Geneva is also said to have been considerable within the memory of man.

There are several instances in mountainous and marshy countries of small lakes having been dried up from different causes—such as the crystallization, or deposit of substances which the waters had previously held in solution; the gradual union of floating islands, and the collection of matter arising from the lake being the seat of animal and vegetable life; but it is evident, from their very slow progress, that the effects produced in these ways cannot be upon a very large scale.

The changes which we have hitherto traced to the action of waters have been of a beneficial kind; but others of a destructive nature are brought about by the same agency. These are the breaking down of steep coasts by the waves, and the throwing up of sand-hills, which the winds afterwards assist in pushing forward and dispersing over the adjacent land. The first is a very common occurrence; the sea detaches fragments from the foot of the cliffs, or else wastes it away, and then the upper parts, deprived of support, fall down. The broken portions that collect at the base, in consequence of these fallings down, serve, more or less, and for a shorter or longer period, according to their position and hardness of material, to protect the cliff from further ravages. The circumstances also which cause the slipping down or breaking away of

masses of rock and earth, among mountains, operate in a similar manner where there are shores of a steep character. Springs filter through and displace the soft strata, and thus the more solid formations are left without support; the consequence is that, at times, large spaces of land slide or fall down from above. It is by such means as these that the 'land-slips,' on the southern shore of the Isle of Wight, have been produced. The same thing happens, but on a far grander scale, upon the coast of the Crimea; whole tracts are there carried down, sometimes bearing upon them the houses of the natives, which have, notwithstanding, been known to escape without injury.

The action of the sea, when the coast is low, and the bottom sandy, leads to very different results. The waves then push the sand forward upon the shore, where, at every ebb of the tide, it becomes partially dried; and the wind, frequently blowing from the sea, drifts it upon the beach. By little and little, hillocks or downs of sand are created, the higher parts of which are continually carried inland; so that unless the inhabitants of the country succeed in fixing them by causing suitable plants to take root in their soil, they move slowly on and overwhelm fields and dwellings with inevitable ruin. It sometimes happens that the sand cast up by the water becomes mixed with marine and other substances, which, being enveloped therein, make what have been denominated *indurated*, that is, *hardened* downs, such as are seen upon the coast of New Holland. Perhaps the most remarkable instance of the mischief occasioned by the moving downs is to be found on the French coast of the Bay of Biscay, south of the river Gironde, where they have already overwhelmed a great number of villages mentioned in the records of the middle age, and not long ago, in the single department of the *Landes*, were threatening ten with unavoidable destruction. One of these villages, named Mimisan, had been struggling against them for twenty years, with the prospect of a sand-hill of more than sixty feet in height visibly approaching it. In 1802, the pools formed by the collection of waters which these downs prevent from flowing into the sea, covered five farming establishments at the village of St. Julien. They have long been over an ancient Roman road leading from Ba-

yonne to Bourdeaux, and which could still be seen forty years back, when the waters were low. The river Adour is now turned to the distance of more than 2000 yards out of its former course. The progress of these downs has been estimated at 60 feet yearly, and in some places, at 72 feet; at this rate, it is calculated that it will require 2000 years to enable them to reach Bourdeaux.

The coast of Elgin or Morayshire, in Scotland, also affords a striking example of the sand-flood; an account of which is given among the notes affixed to Professor Jameson's edition of Cuvier's Theory of the Earth. West of the mouth of the river Findhorn, a district of more than ten square miles in area, (chiefly included in the barony of Coubine,) which, on account of its extreme fertility, was once termed the granary of Moray, has been depopulated and rendered unproductive by the shifting of the sand-hills. It appears that the irruption of the sand commenced about the year 1677; that in 1697, not a vestige was to be seen of the manor-place, orchards, and offices of Coubine, and that two thirds of the barony were already ruined. This irruption came from Mavieston, situated on the shore, about seven miles west from the mouth of the Findhorn, where, from time immemorial, there had been large heaps of sand. These sands, which had formerly been covered with vegetation, were set at liberty by the inhabitants inconsiderately pulling up the bent and juniper for various uses, and they then drifted towards the north-east. When the wind is high, the fine particles are carried even across the bay of Findhorn. In the winter of 1816, a large portion of the only remaining farm, on the west side of the Findhorn, situated in the line of the sand's progress, was overwhelmed. The effects produced by the sand upon the river have been, and still are, of a very obvious kind. Many years ago, its mouth having become blocked up, the water cut out its present more direct channel. By this change, the old town of Findhorn, which originally stood on the east side of the river, was left upon its western bank; and the inhabitants, in consequence, removed the stones of their houses across the new channel, and erected the present village on the eastern side. The site of the old town is now covered by the sea. Even now, when the tide retires, the river almost disappears, being absorbed by

the sand; and owing to the bar formed across its entrance, it is unable, at spring tides, to force its way into the sea, so that it is made to flow back and inundate a considerable extent of land at the head of the bay. Of late, however, the great accumulations of sand have disappeared from Coubine, and the ancient rich soil has, in some places, been left bare, from which it is hoped that the barony will again become serviceable land. Such a result would be rendered much more certain, if, by putting in proper kinds of plants, they were to fix the surface of the Mavieston hills, and so prevent fresh inroads of the sand from that quarter; yet, notwithstanding the destruction that has already happened, the inhabitants are still in the habit of gathering what little bent yet remains.

The same drifting of sand occurs upon several parts of the west coast of the Outer Hebrides, and the prevention of it has been attempted in two ways. Mr. A. Macleod, surgeon of North Uist, has invented the most efficacious plan, which is that of cutting thin square turfs from the neighbouring pasture grounds, and laying them down at intervals of some inches. In the course of a few years the turfs grow together, while the ground, from which they are taken, is little injured, for as the roots remain in it, a new vegetation soon rises up. The other method was introduced by Mr. Macleod, of Harris, and tried extensively upon his estate: it is to plant small bundles of *arundo arenaria*, (sand-reed) about a foot and a half apart; these take root and prevent the drifting, in a certain degree.

Another process, similar in its effects to those which have been already described, but much more extensively destructive, and depending solely upon the action of the wind, is the encroachment of the sands of the Libyan desert upon the cultivated lands of Egypt. These sands, driven by the west winds, have left no soil capable of tillage on any parts of the western banks of the Nile, which are destitute of the shelter of mountains. It would appear that, but for the ridge called the Libyan chain, which borders the left bank of that river, forming to the parts along which it runs a barrier against the sands, the western shores of the Nile would, long ago, have been made uninhabitable. Travellers have given a melancholy picture of the traces which bear witness to the ravages

committed by the sand—the ruins of numerous cities and villages destroyed, and the summits of the minarets of mosques, being still visible above the surface. It is partly to these resistless invasions of the desert that the decline of Egypt from her ancient splendour is to be attributed.

The formation of new islands (to which allusion has been made in a preceding part of this treatise) constitutes a distinct and interesting class among the changes to which the surface of the globe is subject. Those which have been raised up by volcanic agency are, comparatively, few; but those of coral, which owe their origin to marine insects, (of the class of zoöphytes or *plant-animals*) are innumerable. Of the different coral tribes, the most abundant is that named the madreporæ. It is most common in the tropical seas, and decreases in number and variety towards the poles; it surrounds, in vast rocks and reefs, many of the rocky islands of the South Sea and Indian Ocean, and increases their size by its daily growth. The coasts of the islands in the West Indies, of those to the east of Africa, and the shores and shoals of the Red Sea, are encircled with rocks of coral. Several navigators have furnished us with accounts of the curious manner in which these formations take place: the following is extracted from Captain Basil Hall's narrative of his voyage to the Loo Choo islands:—

“The examination of a coral reef, during the different stages of one tide, is particularly interesting. When the tide has left it for some time, it becomes dry, and appears to be a compact rock exceedingly hard and rugged; but as the tide rises, and the waves begin to wash over it, the coral worms protrude themselves from holes which were before invisible. These animals are of a great variety of shapes and sizes, and in such prodigious numbers, that, in a short time, the whole surface of the rock appears to be alive and in motion. The most common of the worms at Loo-Choo is in the form of a star, with arms from four to six inches long, which are moved about with a rapid motion, in all directions, probably to catch food. Others are so sluggish, that they may be mistaken for pieces of the rock, and are generally of a dark colour, and from four to five inches long, and two to three round. When the coral is broken, about high water mark, it is a solid

hard stone; but if any part of it be detached at a spot which the tide reaches every day, it is found to be full of worms of different lengths and colours: some being as fine as a thread, and several feet long, of a bright yellow, and sometimes of a blue colour; others resemble snails, and some are not unlike lobsters in shape, but soft, and not above two inches long.

“The growth of coral appears to cease when the worm is no longer exposed to the washing of the sea. Thus, a reef rises in the form of a cauliflower, till its top has gained the level of the highest tides, above which the worm has no power to advance, and the reef, of course, no longer extends itself upwards. The other parts, in succession, reach the surface, and there stop, forming, in time, a level field with steep sides all round. The reef, however, continually increases, and being prevented from going higher, extends itself laterally in all directions. But this growth being as rapid at the upper edge as it is lower down, the steepness of the face of the reef is still preserved. These are the circumstances which render coral reefs so dangerous in navigation; for, in the first place, they are seldom seen above the water; and in the next, their sides are so steep, that a ship's bows may strike against the rock, before any change of soundings has given warning of the danger.”

Captain Flinders, who, in 1801, made a survey of the coasts of New Holland, has some observations upon the formation of coral islands, particularly of Half-Way island, on the north coast of that region, which show how, after being raised up, they gradually acquire a soil and vegetation:—

“This little island, or rather the surrounding reef, which is three or four miles long, affords shelter from the south-east winds; and being at a moderate day's run from Murray's Isles, it forms a convenient anchorage for the night to a ship passing through Torres' Strait—I named it *Half-way Island*. It is scarcely more than a mile in circumference, but appears to be increasing both in elevation and extent. At no very distant period of time, it was one of those banks produced by the washing up of sand and broken coral, of which most reefs afford instances, and those of Torres' Strait a great many. These banks are in different stages of progress; some, like this, are become

islands, but not yet habitable; some are above high-water mark, but destitute of vegetation; whilst others are overflowed with every returning tide.

"It seems to me, that when the animalcules which form the corals at the bottom of the ocean cease to live, their structures adhere to each other, by virtue either of the glutinous remains within, or of some property in salt water; and the interstices being gradually filled up with sand and broken pieces of coral washed by the sea, which also adhere, a mass of rock is at length formed. Future races of these animalcules erect their habitations upon the rising bank, and die in their turn, to increase, but principally to elevate this monument of their wonderful labours. The care taken to work perpendicularly in the early stages would mark a surprising instinct in these diminutive creatures. Their wall of coral, for the most part in situations where the winds are constant, being arrived at the surface, affords a shelter, to leeward of which their infant colonies may be safely sent forth; and to this, their instinctive foresight, it seems to be owing, that the windward side of a reef exposed to the open sea is generally, if not always, the highest part, and rises almost perpendicularly from the depth of many fathoms. To be constantly covered with water seems necessary to the existence of the animalcules, for they do not work, except in holes upon the reef, beyond low-water mark; but the coral, sand, and other broken remnants thrown up by the sea, adhere to the rock, and form a solid mass with it, as high as the common tides reach. That elevation surpassed, the future remnants, being rarely covered, lose their adhesive property; and remaining in a loose state, form what is usually called a *Key*, upon the top of the reef. The new bank is not long in being visited by sea-birds: salt plants take root upon it, and a soil begins to be formed; a cocoa-nut, or the drupe of a pandanus, is thrown on shore; land birds visit it, and deposit the seeds of shrubs and trees; every high tide, and still more every gale, adds something to the bank; the form of an island is gradually assumed; and last of all, comes man to take possession.

"Half-way Island is well advanced in the above progressive state; having been many years, probably some ages, above the reach of the highest spring tides, or the wash of the surf in the

heaviest gales. I distinguished, however, in the rock which forms its basis, the sand, coral, and shells, formerly thrown up, in a more or less perfect state of cohesion. Small pieces of wood, pumice stone, and other extraneous bodies which chance had mixed with the calcareous substances when the cohesion began, were inclosed in the rock, and, in some cases, were still separable from it without much force. The upper part of the island is a mixture of the same substances in a loose state, with a little vegetable soil; and is covered with the *casuarina* and a variety of other trees and shrubs, which give food to parroquets, pigeons, and some other birds; to whose ancestors, it is probable, the island was originally indebted for this vegetation."

It has been generally believed that the deep perpendicular reefs, very near to which the sounding line finds no bottom, consist wholly of coral; but MM. Quoy and Gaimard have adduced very satisfactory reasons, to prove that the zoöphytes, far from raising from the depths of the ocean perpendicular walls, form only layers or crusts of a few fathoms thickness. They remark that the species which always construct the most considerable banks require the influence of light to perfect them; and it is well known, that all those steep walls common in the equatorial seas, are intersected with narrow and deep openings, through which the sea enters and retires with violence; whereas, if they were entirely composed of madre-pores, they would have no such openings between them, since it is the property of zoöphytes to build in masses that have no interruption. It is besides, difficult to suppose that these animals can support such different degrees of pressure and temperature as they necessarily must, if they exist at such different depths in the ocean. It is, therefore, most reasonable to conclude that the summits of submarine hills and mountains are the bases upon which the zoöphytes form layers and raise up their fabrics; a supposition which perfectly accounts for the great depth of the sea close to the reefs and islands which they have elevated to the surface of the water.

The changes occasioned by the eruptions of volcanoes are very considerable near the seat of action, but they operate over a less extensive field than any of those which have yet been mentioned.

The principal effect of the issue of subterranean fires is the elevation of the surface of the surrounding country; and the size of the mountains themselves must have been prodigiously increased by the matter thrown up during successive eruptions. Some, indeed, have gone so far as to assert that volcanoes are *entirely formed* of this matter; but even if we could admit such a theory, with respect to the isolated volcanoes of Europe, Asia, and the African islands, it would be impossible to extend it to those immense masses in America (Cotopaxi, Pichincha, &c.) which are parts of the great western chain of that continent. There are, nevertheless, very good grounds for concluding that many volcanoes owe their formation to the effects of the fires to which they give vent, and that, previous to the first appearance of those fires, there were no mountains in the places which the volcanoes in question now occupy. It would seem that the breaking out of a volcano, where none before existed, is preceded by a swelling or heaving up of the crust of the earth, owing to the expansive force of the heat, and this explains the cause of new volcanic islands sometimes emerging suddenly from the sea. The phenomenon of the swelling up of the ground was strikingly exemplified when the volcano of Jorullo, in Mexico, arose out of the plain des Playas, in the month of September, 1759. According to the representation of this mountain, annexed to the third volume of M. Humboldt's *Personal Narrative*, the raised up portion of the plain is about two miles in length, and in one part as much as 850 feet above its ancient level; from this part the cone of the volcano shoots up covered with ashes to a further elevation of 830 feet. The raised up ground is covered with thousands of small volcanic cones, from 6 to 10 feet high. We have thus an instance of a mountain 1630 feet in elevation above the plain upon which it stands, having been entirely formed by the heaving up of the earth when the fire originally broke out, and by the accumulation of matter which has since gathered round the principal vent of the eruptions. But the knowledge of such an instance as this does not of necessity lead to the conclusion that mountains so large as Etna, and many other volcanoes, have been entirely created by the process which gave birth

to Jorullo: yet, though it might be rather hazardous to adopt such a conclusion, it is certain that those mountains must have received a vast increase, both in size and elevation, at and since the period, whenever that may have been, at which the subterranean fire first opened a passage through them.

Owing to the repeated discharges of matter upon their surface, and the violent concussions to which they are subject, the external appearance of volcanic mountains is continually varying. This is particularly the case with Etna. Among the accounts of those who have visited it, it would be difficult to find two that at all agree as to the aspect of the great crater and the different eminences about the summit of the mountain. New chasms on the sides also have, at various periods, been opened, and new cones raised up: Monte Russo, thrown up from a plain during the famous eruption of 1669, was estimated by Spallanzani, in 1788, at two miles in circumference, and (somewhat vaguely) at 150 paces in height.

The lava, stones, and ashes spread over the neighbouring country by volcanoes materially elevate its surface. The complete burial of the ancient cities of Herculaneum and Pompeii by the matter ejected from Vesuvius, in the eruption of the year 79, is a circumstance familiar to almost every one. The excavation of these cities in modern days has brought some interesting facts to light; the ruins of Herculaneum were found at a depth of 70 feet below the surface of the ground; and from the number of distinct strata of lava, one above the other, each covered with a layer of rich mould, it appeared that streams of that substance from, at least, six different eruptions had passed over it since the one which occasioned its destruction.

Vast masses of earth sometimes sink down during volcanic eruptions. In the island of Timor, a volcano of considerable elevation is said to have sunk into the ground, leaving a muddy marsh in its place. The *Papandayang*, situated towards the western extremity of Java, was formerly one of the largest volcanic mountains of the island, but the greatest part of it was swallowed up in the earth in the year 1772. It is asserted, that, on the night of this event, an uncommonly luminous cloud was seen to envelop the mountain. Alarmed by this appearance, the inhabitants on the declivities and about the foot of the moun-

tain took to flight, but before they could all save themselves, it began to give way, and the greatest part of it actually *fell in* and disappeared in the earth. A tremendous noise, and the discharge of showers of volcanic substances, accompanied this commotion. It is estimated, that an extent of ground, of the mountain itself and its immediate environs, 15 miles long and 6 broad, was swallowed up in the bowels of the earth.

Of the origin of the volcanic fire, nothing, of course, can be affirmed with certainty; but several explanations have been offered, more or less satisfactory. An attentive observance of the phenomena connected with eruptions, and a close examination of the substances ejected, are necessary to the attainment of any correct views upon the subject. It has been a very generally received opinion that volcanic eruptions are caused by the spontaneous combustion of pyrites; and in support of this solution are cited the experiments which have been made with sulphur and iron filings. A mixture of these substances, after being moistened, has been buried in the ground, where it became gradually heated, and at length took fire, with a loud explosion. The theory, however, which ascribes volcanic action to the inflammation of beds of coal, sulphur, or other matters, near the surface of the earth, has latterly met with less support, and powerful arguments may be urged against it. The great masses of inflammable materials are confined to the secondary and superficial strata; while, on the contrary, there can be no doubt, that the seat of volcanic fire lies far below the surface of the earth, both from the nature of the substances cast out by volcanoes, and the circumstance of the immense quantity of matter that has proceeded from many of them; such a quantity as, had it been withdrawn from the parts near the surface, would, long since, have occasioned those mountains to sink down and disappear. A different theory has been lately brought forward to account for the volcanic fire, and is well set forth and supported in a recent treatise by Dr. Daubeny, Professor of Chemistry in the University of Oxford. It is founded upon the metallic nature of the bases of the earths and alkalies, and the avidity with which these combine with oxygen, producing in that combination a high temperature and strong inflammation. It is supposed, that if

these materials exist in sufficient quantity in the interior of the earth, and a sufficient body of water be admitted to them, judging from the violent effects on a small scale which we are able to produce by experiments, a heat would be engendered quite adequate to occasion all that takes place in volcanic eruptions. Now, under this hypothesis, it is requisite that water should have access to the metallic bases, and it is a curious fact that nearly all active volcanic groups are within a short distance of the sea; while even those in South America, which must be excepted from this remark, are in a range of mountains approaching in parts close to the sea. *Extinct* volcanoes, it is true, are found in situations quite beyond the access of the present ocean; but in the remote and unknown periods of their activity, it may reasonably be inferred that they were near the ocean, if not altogether beneath its surface. A further argument in favour of the present view is, that all the products which chemists know to be the result of the admission of sea-water to the metallic bases, appear under some form or other in every volcanic eruption.

Earthquakes appear to be brought about by the same causes as volcanic eruptions, but their action is much more tremendous than that of the latter. They are frequently accompanied by loud subterraneous noises, and are sometimes so violent that the ground heaves up, and undulates like an agitated sea. They are felt almost at the same instant over a most astonishing extent; though happily, compared with this extent, their destructive ravages are confined within a small range. In those parts which appear to be near the centre of their action, the most calamitous effects sometimes occur; whole cities are destroyed, and their inhabitants buried beneath the ruins; the surface of the ground undergoes violent changes; springs are stopped, and others gush out in new places; fissures are made in the earth; and enormous masses of rock and other materials sink down, or are detached from the mountains. By the earthquake experienced in Chili in 1822, a great line of coast is stated to have been lifted permanently up, to the height of several feet above its former level; while, in the interior of the country, fissures were made in the granite transversely to the direction of the earthquake.

It is generally supposed that earthquakes are produced by the disengagement of elastic vapours, which, endeavouring to escape from their confinement, heave up and agitate the crust of the earth. No doubt can exist of their connexion with volcanic eruptions; their frequency in countries where the latter take place, and the fact of the one often occurring at the same period as the other, sometimes at great distances apart, tend to establish such a connection. This is further shown by the circumstance of the shocks of earthquakes being most severe in places distant from volcanoes; as if the latter were the means of giving vent to that elastic force, which, when pent up, causes such dreadful ravages. It is also worthy of notice, that though earthquakes are sometimes felt towards the interior of continents, their terrible effects occur chiefly along the coasts, as exemplified in the earthquakes of Lima, of Lisbon, of Caraccas, and many others.

Such are the principal changes which the surface of the globe is now undergoing. It is evident, notwithstanding what some have been inclined to assert, that they could not have brought about those grand revolutions which formerly visited the earth, and in which such multitudes of the animal race were consigned to destruction. The whole of them are insufficient to alter, in any perceptible degree, the level of the sea, still less to have occasioned an overwhelming of the land by that element. Some philosophers have endeavoured to prove that a gradual and general lowering of the level of the sea takes place, and have appealed to certain observations which, if correct, tend to establish the fact of a diminution of the waters along the northern shores of the Baltic. But it must not be forgotten, that though in some places the ocean has retired, or sunk in level, in others it has encroached upon the land; while it is known that many harbours of the Mediterranean have preserved exactly the same level since the time of the ancients. It is plain, therefore, that all variations upon the coasts of the ocean are merely of a local kind, and that if the different accounts are balanced, we must arrive at the conclusion, that the general volume of the ocean, and perhaps even its superficial extent, suffer neither increase nor diminution.

On the Ocean—its Saltness, and Temperature, Tides, and Currents.

THAT vast body of water which surrounds the continents, and is the common receptacle of their running waters, is indispensably necessary to the support of animal and vegetable existence upon the earth. Its perpetual agitations purify the air, and the vapours which the atmosphere draws up from its surface, being condensed and dispersed through the upper regions, form clouds, which are the source of a constant supply of rain and moisture to the land. The ocean also, by the facilities for communication which it offers, is the means of uniting the most distant nations, while it enables them to interchange with mutual advantage the productions of their several climates.

The bottom of the sea appears to have similar inequalities to the surface of the continents; the depth of the water is, therefore, extremely various. There are vast spaces where no bottom has been found, but this, of course, does not prove that the sea is bottomless, because the line is able to reach but a comparatively small depth. Lord Mulgrave, in the Northern Ocean, let down a very heavy sounding lead, and gave out with it nearly 4700 feet of rope without finding the bottom; and Mr. Scoresby mentions having sounded in the Greenland sea as much as 7200 feet. Such experiments, however, must be of very doubtful character; it is well known how much more easily bodies may be moved along in the water than in the atmosphere, and, consequently, any current would be sufficient to carry the lead with it, and so draw the rope out of a perpendicular direction. If we were to found our opinion upon analogy, we might conclude that the greatest depth of the ocean is, at least, equal to the height of the loftiest mountains, that is, between 20,000 and 30,000 feet.

The level of the sea, if it were not for the action of external disturbing causes, would be the same every where at the same instant, owing to the equal pressure exerted by the particles of a fluid upon each other in every direction. The figure assumed by the ocean would, therefore, exhibit the true surface of our planet, that of an oblate spheroid. But it is evident that no general level of this kind can ever exist, because the tide at any

given moment is at very different heights in different parts of the ocean. The level is also continually being disturbed by the operation of the wind in particular regions. Independent, however, of these circumstances, it would appear that in gulfs and inland seas which have only a slight communication with the ocean, the level of the water is usually more elevated than in the latter. This seems to be more especially the case if the only openings of these gulfs are towards the east; and it is attributed with reason to the accumulation which arises from the water being driven into these confined inlets by the general movement of the sea from east to west, a movement to which allusion will be made presently. When the French engineers were in Egypt, they made observations, according to which the waters of the Red Sea, on the east side of the isthmus of Suez, were $32\frac{1}{2}$ feet higher than those of the Mediterranean on the opposite shore of the same isthmus. M. Humboldt made observations of a similar kind upon the isthmus of Panama, and his conclusion is that the waters of the Gulf of Mexico are from 20 to 23 feet higher than those of the Pacific on the other side. Of certain inland seas the level varies with the seasons; the Baltic and the Black Sea, which are in fact almost lakes, swell in the spring, from the abundance of water brought down to them at that period by the rivers.

The general colour of the sea is a deep bluish green, which becomes clearer towards the coasts. This colour is thought to arise entirely from the same cause as the azure tint of the sky; the rays of blue light, being the most refrangible, pass in the greatest quantity through the water, which, on

account of its density and depth, makes them undergo a strong refraction. The other colours exhibited in parts of the sea depend on causes which are local, and sometimes deceptive. The Mediterranean in its upper part is said to have at times a purple tint. In the Gulf of Guinea the sea is white; around the Maldive Islands it is black; and in some places it has been observed to be red. These appearances are probably occasioned by vast numbers of minute marine insects, by the nature of the soil, or by the infusion of certain earthy substances in the water. The green and yellow shades of the sea proceed frequently from the existence of marine vegetables at or near the surface.

The water of the sea contains several extraneous substances, in proportions varying in different places. The component parts, in addition to pure water, are commonly muriatic or marine acid, sulphuric acid (vitriol), fixed mineral alkali, magnesia, and sulphated lime. By boiling or evaporation in the air, common salt (muriate of soda) is obtained, which for salting meat is preferred to the salt of springs. The saltiness of the sea appears, with some local exceptions, to be less towards the poles than near the tropics; but the difference is very slight, and perhaps the observations made are not sufficiently numerous to justify any positive general conclusions. It is probably occasioned by the melting of the ice in the polar seas. Dr. Thomson (*Work on Chemistry*) states the proportion of salt in water taken up by Lord Mulgrave at the back of Yarmouth sands, at 3.125 per cent. of the weight of the water. He also gives, from the accounts of different observers, the following proportions:—

Quantity of saline matter.							
N. Lat.	80°	(60 fathoms under ice)	3.54	per cent.	S. Lat.	49° 50'	4.16 per cent.
"	74	" "	3.60	"	"	46	4.50 "
"	60	" "	3.40	"	"	40 30	4.00 "
"	45	" "	4.00	"	"	25 54	do. "
"	39	" "	do.	"	"	20	3.90 "
"	34	" "	do.	"	"	1 16	3.50 "
"	14	" "	do.	"	"		

Mr. Scoresby, in north latitude $77^{\circ} 40'$, and east longitude $2^{\circ} 30'$, found, in a quantity of water taken from the surface, the proportion of saline matter 3.56 per cent. A statement in the Edinburgh Philosophical Journal gives the proportion in north lat. $64^{\circ} 26'$, east long. $0^{\circ} 38'$, 3.54 per cent.; in north lat.

$78\frac{1}{2}^{\circ}$, east long. $6\frac{1}{2}^{\circ}$, $3^{\circ} 88'$; and in north lat. $78^{\circ} 35'$, east long. 6° , $3^{\circ} 27'$. Some observations which have been made tend to prove that the sea is less salt at the surface than towards the bottom.

The following table of the proportional specific gravities of different kinds of water, explains the reason of bodies

being so much more buoyant in the sea than in other water :—

Distilled water . . .	1.000
Purest spring water . .	1.001 to 1.005
River water	1.010
Sea water	1.028

The degree of saltness in particular parts of the sea frequently varies from temporary causes. The violent tropical rains have an effect in diminishing it, especially near coasts, where an increased volume of fresh water is brought down by the rivers. The Baltic is at all times less salt than the ocean, and when a strong east wind keeps out the North sea, its waters are said to become almost fit for domestic uses. The most curious phenomenon of all is that of springs of fresh water rising up in the midst of the sea; Humboldt mentions that in the Bay of Xagua, on the southern coast of Cuba, springs of this kind gush up with great force at the distance of two or three miles from the land.

The bitterness which exists in seawater, but apparently not beyond a certain depth, is with much probability considered to be owing to the vegetable and animal matter held there in a state of decomposition.

Water being a bad conductor of heat, the temperature of the sea changes much less suddenly than that of the atmosphere, and is by no means subject to such extremes as the latter. It may

safely be affirmed that the temperature never in any season, or under any latitude, exceeds eighty-five or eighty-six degrees of Fahrenheit's thermometer. The existence of banks or shallows has a local effect in diminishing the temperature of the ocean, but the great agents in modifying it are currents, which mingle together the waters of different depths and regions. Thus the Gulf stream, as it is termed, which sets into the Gulf of Mexico, is much warmer than the neighbouring parts of the sea; the current of Chili is just the reverse. The following tables are extracted from M. Humboldt's Personal Narrative, (Vol. II.;) the experiments from which No. I. was drawn up, were made during the passage from Spain to the New Continent, between the 9th of June and 15th of July 1799 :—

(No. I.)

North lat.	West long.	Temp. of the Atl. ocean at its surface.
39° 10'	16° 18'	59° 00' Fahr.
34 30	16 55	61 34
32 16	17 4	63 86
30 36	16 54	65 48
29 18	16 40	66 74
26 51	19 13	68 00
20 8	28 51	70 16
17 57	33 14	72 32
14 57	44 40	74 66
13 51	49 43	76 46
10 46	60 54	78 44

(No. II.)

Table of the Temperature of the Atlantic Ocean in different degrees of Longitude.

Latitude.	Longitude.	Temp. of the Ocean.	Period of the Observation.	Observers.	Mean Temperature of the Air in the Basin of the Sea
0° 58' S.	27° 34' W.	80.96 Fh.	Nov. 1788	Churruca	80°·6 (Cook.)
0 57	30 11	81.86	April 1803	Quevedo	
0 33	21 20	81.86	March 1800	Perrins	
0 11 N.	84 15	82.40	Feb. 1803	Humboldt	
0 13	51 42 E.	80.78	May 1800	Perrins	69·8 (La Pérouse and Dalrymple.)
25 15 N.	20 36 W.	68.00	June 1799	Humboldt	
25 29	39 54	70.88	April 1803	Quevedo	
25 49	26 20	69.26	March 1800	Perrins	
27 40	17 4	70.88	Jan. 1768	Chappe	
28 47	18 17	74.30	Oct. 1788	Churruca	54·86 (Cook and d'Entrecasteaux.)
42 34 N.	15 45 W.	51.98	Feb. 1800	Perrins	
43 17	31 27	59.90	May 1803	Quevedo	
43 58	13 7	60.62	June 1799	Humboldt	
44 58	34 47	54.86	Dec. 1789	Williams	
45 13	4 40	59.90	Nov. 1776	Franklin	
48 11	14 18	57.74	June 1790	Williams	

These tables refer only to the Atlantic ocean; but the experiments which have been made in the South sea, and in the Indian ocean, show that within a certain distance of the equator, the general temperature of the sea follows nearly

the same rule in corresponding latitudes. Within the tropics there is no sensible difference in north and in south latitudes; there is very little even as far as the thirty-fifth and fortieth degrees; but, when we advance into high lati-

tudes, there can be no doubt that the sea is colder in the southern than in the northern hemisphere. Ice extends from five to eight degrees of latitude farther from the south than from the north pole, owing, it is probable, to the almost entire absence of land near the Antarctic circle; while the north pole is so nearly surrounded by land, that the ice of the Arctic ocean is shut up, and cannot be carried forward to such a distance by the current which sets towards the equator.

Bays, inland seas, and the spaces among clusters of islands, where the action of the waves is more confined, and the water usually of less depth, are the most favourable places for the production and accumulation of the marine ice. It is on this account that the navigation of the Baltic is annually stopped by the ice in a latitude not more northerly than that of tracts which in the main ocean are always open to the passage of ships. In severe winters, people may travel in sledges across the entrance of the Gulf of Bothnia (lat. 60°) which, including the numerous small intervening islands, is a distance of a hundred and fifteen miles. The body of ice accumulated in Sir James Lancaster's sound has defied all the attempts that have been made to accomplish the north-west passage from the Atlantic to the Pacific.

The ice of the polar seas assumes a great variety of shapes and appearances. The vast and thick sheets which are met with in high latitudes are called *fields* by navigators; they are so extensive, that their boundaries cannot be seen from a ship's mast-head; and Captain Cook found a chain of them joining Eastern Asia to North America. Sheets of less extent than fields are called *floes*. *Bergs* are islands of ice, considerably elevated above the water; and though of the most various forms, commonly perpendicular on one side, and sloping gradually down on the other, in height they are sometimes as much as two hundred feet*. There are two ways of explaining the formation of these bodies. The large masses of ice in the Polar seas, when crowded together by winds and currents, exert such an enormous pressure upon each

other, that they are frequently broken, and the fragments are piled up so as to form mounds and ridges of considerable elevation; it is thus that many of the small ice-bergs originate. There is no doubt, however, that the most bulky of these bodies are detached portions of vast glaciers, such as abound on the precipitous coasts of Greenland and Spitzbergen, broken off in consequence either of their own weight, or the undermining action of the waves, and then carried by winds and currents to other parts of the ocean.

When the summer has well advanced, the masses of ice which have been frozen together during the winter gradually separate, and clear spaces of water are left. As soon as the end of September, these open spaces again begin to freeze over; but before this effect commences, the temperature of the air must be very much lowered, owing partly to the freezing point of sea being three and a half degrees (Fahrenheit) below that of common water, but more especially to the surface which the water presents to the atmosphere being repeatedly changed before its temperature is sufficiently reduced for it to freeze. This change in the surface, which is greatly assisted by the agitation of the sea, takes place in consequence of the particles of a liquid body becoming specifically heavier as they get cooled, so that they descend and are succeeded by warmer particles.

There are three kinds of movements constantly going on in the waters of the sea:—1. The agitations which its surface undergoes by the action of winds—2. Tides, which are the result of the attraction exercised on the water by the sun and moon—3. Currents, which arise from different causes, some of them existing within the element itself.

1. As the particles of a fluid press equally in every direction, it follows that when a portion of the surface of the water is displaced by a wind, the adjoining water instantly rushes in to restore the equilibrium or balance which has been destroyed. This accounts for the formation of *waves*. When a violent impulse has thus been communicated, the waves continue in motion for some hours after the gale has entirely subsided, on the same principle as a pendulum continues to swing for some time after it has been set in action. Yet the agitation occasioned by winds extends to comparatively but a little way below

* Experiments made in the Arctic Seas show that of a piece of floating ice, the proportion above water is generally about one-seventh of the thickness of the whole mass. It must not, however, be supposed from this, that an iceberg two hundred feet out of the water exhibits only one-seventh of its height, because these bodies are frequently aground.

the surface of the water: divers say that, in the roughest weather, it is calm at the depth of ninety feet.

2. The *tides* proceed from the attractive forces of the sun and moon, which diminish the gravity of the waters of the

ocean, or, which is the same thing, draw or lift up the waters toward themselves. Let E (fig. 1.) represent the earth and M the moon; since the power of gravity increases as the square of the distance diminishes, it is evident



Fig. 1.

that the waters at A, the part of the earth nearest the moon, will most feel the effect of her attraction, and will be raised up to B; while those on each side of A, being farther off, will be less raised. But besides the difference occasioned by a greater or less distance, the more oblique or slanting the line of attraction, the less will be the elevation of the water acted upon, till at last the water towards and under the circle CEF will not only not be elevated but will be lowered. The reason of this is, that the force of attraction acts in straight lines; and, therefore, if we draw two straight lines from the moon's centre, MC, MF, to represent this force acting on the parts C and F, it is obvious that the water at C and at F will not be raised, but depressed by being drawn away from C to D and from F to H; and so of every part of the circle CEF. In the same manner, the water at D and H will pass to G and I, and thus the ocean will be disposed in a spheroidal form CDGBIHF. But the water will, at the same time, rise on the side of the earth away from the moon, because the earth's centre being more strongly drawn towards the moon than the point N, recedes from N, which is the same in effect as if the water at N receded or rose up from the earth's centre. The ocean, therefore, will assume a spheroidal form, CKF, on the side away from the moon, as well as on the one facing her. Thus, if we draw a line MAK from the moon's centre through the centre of the earth, the two points B, K, where it touches the earth's surface, will be those of *high water*; and if we take two more points C, F, equally distant from each of the first two, they will be points of *low water*. By the earth's rotation on its axis the part F will be carried to A and the part C to N; matters will then be just reversed, and it will be high water at F

and C, and low water at A and N. According to this it should be high water at any place in the open sea, when the moon is upon the meridian of that place, and low water when the moon is upon a circle cutting the meridian in question at right angles; but, in fact, the greatest and least heights of the water at such a place do not occur till about three hours *after* the periods fixed in this supposition. The delay is thus explained: the elevated parts of the sea have received such an impulse towards ascent, that they continue to rise after the earth's rotation has carried them from under the line of the direct attraction of the moon; this impulse being also aided for a time by the moon continuing to attract the water upwards, though in a less degree.

As the moon crosses the meridian of a place about every twenty-four hours fifty minutes and a half, the sea in that space of time ebbs twice and flows twice all over the world, although much less towards the poles than within the tropics, where the waters are under the direct line of the lunar attraction.

In the above remarks we have spoken only of the moon, because, though the sun is so very much larger than the moon, yet the latter, on account of her nearness to our planet, has the most powerful effect upon the tides; it is calculated that her influence is nearly triple that of the sun. The sun, however, acts upon the ocean in the same manner, though in a less degree. When these two bodies unite their influence, which they do at the seasons of new and full moon, the tides naturally rise the highest, and are then called *spring tides*; but when the moon is in her quadratures, or quarters, the action of each of the two luminaries is directly opposed to that of the other; the tides are then of course the lowest, and are called *neap*

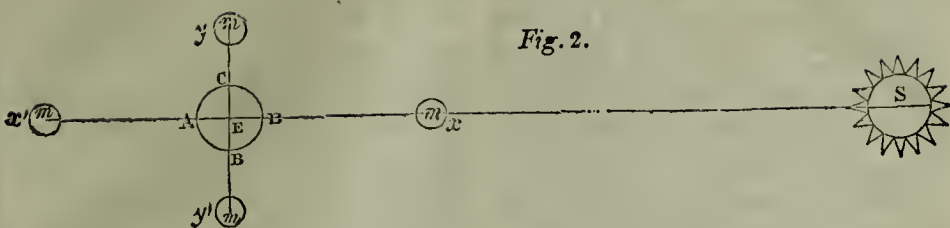


Fig. 2.

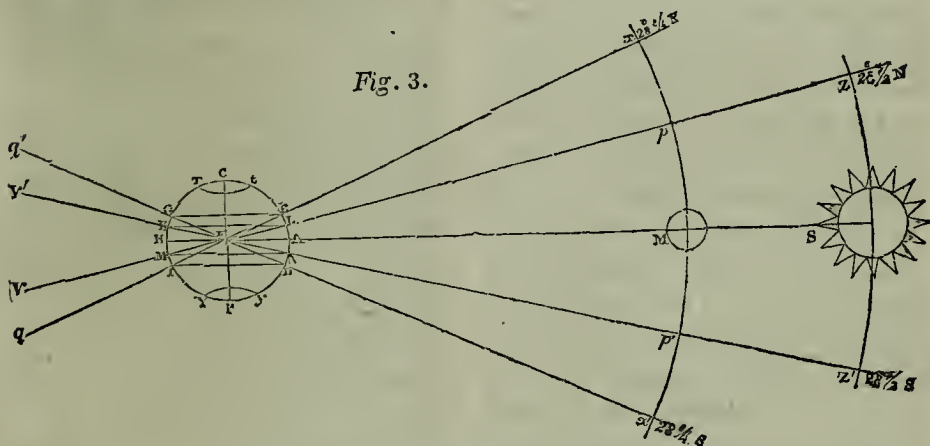
tides. To explain this more clearly, let E (fig. 2) be the earth, S the sun, and *m* the moon; when new, the moon is situated at *x*, when full at *x'*, and when in her quadratures at *y* and *y'*. It results, from what has been already said, that, both at new and full moon, the sun and moon will each assist the other in raising the ocean round A and D, and depressing it at C and B; but when the moon is in her quadratures, her tendency is to raise the waters at C and B and depress them at A and D; while that of the sun is exactly the reverse. During the moon's circuit round the earth, the

spring and the neap tides each occur twice, and one after the other.

If the earth were entirely covered by a sea of uniform depth, and the sun and moon moved always in the plane of the equator, the region of the highest tides would always be directly under the equator, while at the poles there would never be any tide whatever. But the changes that occur in the positions of the sun and moon, and several other circumstances, prevent the tides from taking place in so uniform a manner.

In figure 3, let us suppose A E H to be the equator, and C and F the poles

Fig. 3.



of the earth, and let M, the moon, and S, the sun, both be in the plane of the equator; in this case the water will be higher at H and A, than in any other places, and most depressed under the circle C E F. By the earth's rotation, E will come to A, and it will be high water at E, but C and F, the poles, suffer no change of position from the earth's rotation, and the waters there will, consequently, remain just as before. If the sun and moon, therefore, were to remain constantly in the plane of the equator, the highest tides would always be at A, E, H, &c., that is, under the equator; while, as C and F would always be situated the same with respect to the sun and moon, it would always be low

water at the poles, that is, they would never have any tides at all. The sun and moon, however, are continually changing their positions, with respect both to the equator and to each other, and corresponding variations are produced in the tides. The moon, for instance, is sometimes as much as $28\frac{1}{2}$ degrees on each side of it. Suppose her to be situated at *x*, $28\frac{1}{2}$ degrees north of the equator, draw a line from *x* through the centre of the earth, and let it come out at the opposite side of the earth, the points B and I will have the highest tides, and as the earth turns round, all the parts of the circles G B and I D will successively come to B and I. The waters, under those two circles, will,

therefore, have the highest lunar tides, (when the moon is at x or x') and the waters, under the circles Tt and Yy , will, in turn, be the most depressed. Results of a similar kind are obtained if we notice the changes of the sun's position. In the course of a year, that luminary ranges nearly $23\frac{1}{2}$ degrees on each side of the equator. Suppose him to be situated at z , $23\frac{1}{2}$ degrees north of it: a line drawn from him, through the earth's centre to the other side, will pass through L and M , and the parts under the circles LK and MN will, while the sun is at z or z' , experience the highest solar tides. If, therefore, at the time when the sun is situated at z , or z' , the moon happens to be at x , x' , q , or q' , the sea, under the four circles GB , ID , LK , and MN , will, as the earth moves round, have the highest tides on the globe; the tides of GB and ID being, however, higher than those of LK and MN ; since the moon's attraction is more powerful than that of the sun. If again, while the sun is at z , or z' , the moon happens to be at p , p' , v , or v' , the forces of both will combine to raise the tides highest under the two circles LK , MN ; and when both luminaries are on the equator together, the circle AEH (that is, the equator) will, alone, be that of the highest tides. It must at the same time be kept in view, that whenever the sun and moon are not situated at the same distances from the equator, so that the circles of their highest tides do not coincide or fall together, allowance must be made for their attractive forces *counteracting*, in some degree, each other's effects upon the ocean; and as the moon completes her range on each side of the equator in about $29\frac{1}{2}$ days, while the sun, to complete his, takes nearly $365\frac{1}{4}$ days, their combined motions must produce continual irregularities in the tides. Taking one year with another, the mean monthly range of the moon on each side of the equator is the same as the annual range of the sun ($23^\circ 28'$); the *highest* tides are, consequently, within the tropics, and the *least* within the arctic and antarctic circles.* Within the tropics, the

flood tide passes from east to west, (following the apparent course of the sun and moon,) but as the torrid zone is the seat of the highest tides, the flood in the northern temperate zone comes from the south, and in the southern temperate zone from the north. To this rule there are, nevertheless, local exceptions, caused by those derangements of the tide which we are now going to mention.

Of all irregularities in the tides, those are the greatest which are occasioned by the obstacles offered by the land to the ebb and flow of the waters. The impediments created by shallows in the ocean, and by the shores, bays, gulfs, and promontories of islands and continents are such, that the tides are greatly delayed, altered both in degree and in direction, and in many places so accumulated, that they rise to heights far exceeding what is witnessed in the open ocean. On the coasts of the islands of the South Sea, there are regular tides of only one or two feet in elevation; but on the western shores of Europe, and on the eastern shores of Asia, the tides are very strong, and have many variations. On the northern coasts of France, the flow being confined in a channel, and repelled also by the opposite coasts of England, rises to a surprising height; at St. Maloes, in Bretagne, it is said, even to 50 feet. The tide of the German Ocean is twelve hours in travelling from the mouth of the Thames to London Bridge, where it arrives about the time that there is a new tide in the German ocean. This is one instance out of many, of the effect produced upon the tide when it has to pass along a narrow channel, and to overcome an opposing current.

The explanation that has been given

* We have already shown, that it is high water at any place twice in every 24 hours $50\frac{1}{2}$ minutes. When a place is on the *same side* of the equator as the moon, the tide, which is produced while the moon is *above* the horizon of the place, will *exceed* the tide which is produced while the moon is *under* the horizon of the place; but when a place is on the opposite side of the equator to the moon, the effect is exactly the reverse. This is explained in the following way:—

LK (fig. 3) is a parallel of north, and MN a parallel of south, latitude; $CHFA$ is a meridian; and when the moon is at K , LK and MN are also circles of the highest tides. Each place under those circles has high water twice in 24 hours $50\frac{1}{2}$ minutes—once, when it is under L or M —and again, when it is under K or N ; but, under M and N , the tides are *not so high* as at L and M , because we have before shown that L and M are the points of the highest tides when the moon is at p . Now, to places under L and N , the moon is *above* the horizon—and, to places under M and K , she is *below* the horizon; and, therefore, when the moon is at p , north of the equator, a place under LK , a parallel of north latitude, will have its *greatest high water* when the moon is *above* the horizon, but a place under MN , a parallel of south latitude, will have its *greatest high water* when the moon is *below* the horizon. When the moon is at p' , south of the equator, these effects will be just reversed. In summer, when the sun's declination is considerably north, the afternoon tides, north of the equator, are higher than the morning tides; in winter, the morning tides exceed those of the afternoon.

of the manner in which tides are created in the ocean, will enable us to perceive why it is that, in some gulfs and inland seas, there are either no tides, or such trifling ones as to be scarcely discernible. In figure 1, the waters at A are brought to B, not only by the moon raising up the parts immediately under her, but also by her drawing obliquely towards B the parts distant from B, and by the lateral flowing of the neighbouring waters (*p n*, for instance) towards B, which results from their being less attracted by the moon, and, therefore, heavier than those at B. Being heavier than B, they press upon and flow towards that part. In small collections of water, the moon acts with the same line of attraction, or nearly so, upon every portion of the surface at once, and, therefore, the whole of the waters being equally elevated at the same period, no part of them is ever higher than the other. This is one reason why the Baltic has no perceptible tides, and why even those of the Mediterranean are hardly visible.* But in addition to this, the two seas in question are so circumstanced that they cannot receive tides from the Atlantic: 1st, because their entrances are not turned towards the main direction of the Atlantic tide; 2ndly, because their entrances are so narrow, that the quantity of tide which that ocean can, in a few hours, impel into them, is insufficient, after being spread over the extensive surfaces of the two seas, to raise their level at all perceptibly. The Greeks, who accompanied Alexander the Great in his expedition to the east, having never been on any other coasts than those of the Mediterranean, were seized with complete consternation on first beholding the retreat of the strong tide which the Indian ocean sends into the river Indus. In gulfs which are differently circumstanced with respect to the direction of their entrances, and which have openings wider, as compared with their extent, the tides propagated from the ocean are sensibly felt. Hudson's and Baffin's Bays, and the Red Sea, are examples which prove the correctness of this observation.

Currents and winds (especially the latter) have, according to their direction, an influence either in quickening or retarding the tide; indeed a powerful wind will sometimes keep a tide out of very narrow channels. On the contrary, a strong wind coming from the same quarter as the tide, will raise it several feet above its usual level.

The causes which render the movements of the tides complex and irregular, may thus be summed up under four heads—1. The variations in the positions of the sun and moon, with respect to the equator and to each other. 2. The obstacles presented by the land; 3. by winds; and 4. by currents. The existence of these causes renders it impossible to lay down any general rule for calculating the level, either of high or of low water, in different latitudes.

3. *Currents* in the ocean may be occasioned in various ways: they may arise from an external impulse, (a gale of wind for instance); from a difference in temperature or saltness between two parts of the sea; from the periodical melting of the polar ice, or from the inequality of the evaporation which the surface of the sea undergoes in different latitudes. These causes may produce either constant or occasional currents, and, according as they act in concert or in opposition, will their effects be various.

The most remarkable currents are those which continually follow the same direction. There is one which sets regularly from each of the poles towards the equator; and when we get within twenty-eight or thirty degrees of the line on either side, a general movement is observed in the ocean, in a direction nearly from east to west. The existence of the two polar currents is proved by the floating of masses of ice from the frigid into the temperate regions: these masses are, at times, seen as low as the forty-fifth, or even the fortieth degree of latitude. It was the opposition of the polar current which principally occasioned the failure of the attempt made last year under Captain Parry to reach the north pole; before they desisted from their efforts, the expedition found that, as they advanced over the ice, they were being drifted *southward*, at a rate faster than that at which they were travelling northward. It is equally certain that a tropical current exists, judging not only from the direction of bodies floating on the water, but also from the circumstance that vessels, in crossing from

* The little tide which there is in the Mediterranean, seems to be formed chiefly in the part extending to the east of Malta, and to proceed northward into the Gulf of Venice. M. D'Angos observed that at Toulon, on the coast of France, the sea rose a foot about three hours and a half after the moon passed the meridian.

Europe to America, descend to the latitude of the Canary Islands, where they fall into a current and are carried rapidly to the west. In going from America to Asia across the Pacific, a similar effect is observed. It might be supposed that this was due solely to the trade-winds, but such is not the case: for it is quite possible to distinguish their effect from that of the currents, since the progress of the vessel is quicker than it could be with the aid of the wind alone.

The origin of the polar currents is, no doubt, in a great measure, to be referred to the centrifugal force which is the result of the earth's rotation. (See *Mathematical Geography*, chap. 8.) It may be further explained, when we reflect that the water towards the poles, both on account of its lower temperature and its being less attracted by the heavenly bodies, is *heavier* than the water in the tropical regions, and, moreover, that the heat of the torrid zone occasions a much more powerful evaporation of the sea than is elsewhere experienced: the consequence is, that the waters nearer the poles will move towards the equator, in order to restore the equilibrium which has, in these several ways, been destroyed. The tropical current may also, though in another manner, be explained as proceeding from the earth's rotation. The waters, as they advance from the polar seas, pass from regions where the rotatory motion of the earth's surface is very slight, to those where it is exceedingly rapid; they cannot immediately acquire the rapid motion with which the solid parts of the earth revolve in the tropical regions, and they are, accordingly, left rather behind, that is, to the *westward* (the earth turning round from west to east). The ocean, consequently, appears to retreat from the western, and advance upon the eastern coasts of the continents, or, in other words, to have a general movement from east to west; and the effect is very much assisted by the constant blowing of the trade winds.

We will now explain the modifications or changes which this grand movement in the ocean undergoes, in consequence of the obstacles presented by the land to its free progress. When it meets with shores or narrow straits to impede or turn aside its course, it forms strong and even dangerous currents. The eastern coast of America, and the West India Islands, constitute a sort of dyke to the general westward motion of the

Atlantic; and it will be seen, if we refer to a map, that from Cape St. Roche, which has about five degrees of south latitude, the coast of South America stretches away in a continued line to the north-west, as far as the isle of Trinidad. Owing to this shape of the coast, the waters, as far as the tenth degree of south latitude, are, when they approach America, carried away in a current to the north-west. This current afterwards enters the gulf of Mexico, through the strait formed by the western end of Cuba, and the opposite peninsula, (from this part it is called, by navigators, the *Gulf-stream*,) and follows the bendings of the Mexican coast, from Vera Cruz to the mouth of the Rio del Norte, and thence to the mouths of the Mississippi, and the shoals west of the southern extremity of Florida. It next takes a new direction to the north, and rushes impetuously into the gulf of Florida. M. Humboldt observed in the month of May 1804, in the 26th and 27th degrees of latitude, that its velocity was eighty miles in twenty-four hours, although, at the time, there was a violent wind against it. At the end of the gulf of Florida, (north lat. 28°) it runs to the north-east, at the rate, sometimes, of five miles an hour. It may always be distinguished by the high temperature* and the saltness of its waters, their indigo-blue colour, and the quantity of sea-weed floating on the surface, and also by the heat of the surrounding atmosphere. The rapidity and temperature of the *Gulf-stream*, diminish towards the north, while, at the same time, its breadth increases.† Its further progress northward is at last checked by the southern extremity of the great bank of Newfoundland, in the 42d degree of latitude, where it turns suddenly to the east. It afterwards continues moving towards the east, and the east-south-east, as far as the Azores islands; and

* Humboldt observes that "the waters of the Mexican Gulf, forcibly drawn to the north-east, preserve their warm temperature to such a point, that at forty and forty-one degrees of latitude, he found them at seventy-two degrees and a half (Fahrenheit); when, out of the current, the heat of the ocean at its surface was scarcely sixty-three degrees and a half. In the parallel of New York, (forty-one degrees north) the temperature of the *Gulf stream* is, consequently, equal to that of the seas of the tropics in the eighteenth degree of latitude."

† Its breadth in latitude twenty-eight degrees and a half is seventeen leagues; (3.46 miles to a league) in the parallel of Charles town, (thirty-three degrees, nearly) from forty to fifty leagues; and on the meridian of Corvo and Flores, the westernmost of the Azores islands, it is one hundred and sixty leagues.

thence it turns towards the straits of Gibraltar, the Isle of Madeira, and the group of the Canaries, till, on reaching the parallel of Cape Blanco, it completes the round by mixing with the grand westerly current of the tropics. It is probable, however, that a branch still keeps on its course to the south and south-east, along the coast of Africa; for it is well known that ships, if they approach too near the shore, are drawn into the gulf of Guinea, and with difficulty get out again. We thus see that between the parallels of 11 and 43 degrees, the waters of the Atlantic are carried on in a continual whirlpool. Humboldt remarks that, supposing a particle of water to return to the same place from which it departed, "we can estimate, from our present knowledge of the swiftness of currents, that this circuit of three thousand eight hundred leagues is not terminated in less than two years and ten months. A boat, which may be supposed to receive no impulse from the winds, would require thirteen months, from the Canary Islands, to reach the coast of Caraccas; ten months to make the tour of the Gulf of Mexico and reach Tortoise Shoals, opposite the port of the Havannah; while forty or fifty days might be sufficient to carry it from the straits of Florida to the bank of Newfoundland. It would be difficult to fix the rapidity of the retrograde current from this bank to the coasts of Africa: estimating the mean velocity of the waters at seven or eight miles in twenty-four hours, we find ten or eleven months for this last distance." It is a curious fact, that towards the close of the 15th century, before Europeans were acquainted with the existence of America, two bodies belonging to an unknown race of men were cast by the Gulf-stream on the coasts of the Azores, and pieces of bamboo were brought by the same current to the shore of the small island of Porto Santo; by these circumstances, Columbus is said to have been strengthened in his conjectures with respect to the existence of a western continent.

An arm of the Gulf-stream in the 45th and 50th degrees of latitude, runs to the north-east, towards the coasts of Europe, and becomes very strong when the wind has blown long from the west. The fruit of trees which belong to the American torrid zone is every year deposited on the western coasts of Ireland and Norway; and on the shores of the

Hebrides are collected seeds of several plants, the growth of Jamaica, Cuba, and the neighbouring continent. The most striking circumstance, perhaps, is that of the wreck of an English vessel, burnt near Jamaica, having been found on the coast of Scotland.

There are various currents in the Pacific and Indian oceans. The general westward motion of the former is impeded by a numerous archipelago, and hence it receives different directions. A strong current sets to the west, through each of the two straits which respectively separate New Holland from New Guinea and from Van Diemen's Land. It then gets diverted, and flows northward along the coast of Sumatra, till it reaches the bottom of the Bay of Bengal. The following appears to be the reason of its taking this course:—the general impetus of the Pacific towards the west, being encountered by New Holland and the numerous East India Isles, is broken and dispersed; while the westerly motion of the Indian sea has not, in so early a stage, acquired much strength; the polar current from the south, at the same time, presses upon the wide opening which the Indian sea presents to that quarter, and the waters on the eastern verge of that sea are, therefore, pushed into the Bay of Bengal. In the neighbourhood of Ceylon and the Maldivé islands, however, the tropical motion has become powerful enough to resist the polar current. The westerly current then recommences, but is again turned out of its line and made to flow to the south-west, by the chain of islands and shallows, which reaches from the extremity of the Indian peninsula to Madagascar. After passing Madagascar, it dashes against Africa, and at the termination of that continent, mingles with the general motion of the waters.

A current afterwards sweeps from the Atlantic into the Pacific ocean, through the straits of Magellan. There can be little doubt that this is a branch of the general current from the south pole; though, at the same time, it may be partly the result of the westerly movement of the Atlantic, which, being checked by the shores of Brazil, flows to the south-west, along the South American coast.

There is a question connected with the currents of the Arctic ocean, which has engaged a good deal of attention, and been considered difficult to explain:

it is from what quarters the timber can come which is found floating on the polar seas in such large quantities, and so much of which is thrown ashore on the northern side of Iceland*. The few specimens seen of the growth of Mexico and Brazil, must have travelled to the north by means of the Gulf-stream of which we have spoken; the rest (principally pines and firs) most likely comes from Siberia and North America, along the shores of which it is drifted till it arrives at the opening into the Atlantic, in the midst of which Iceland is placed.

The existence of *under currents* different from, and even opposite in their direction to those on the surface is, by no means, improbable in some cases, though it is a matter not admitting of proof. It has been thought that the Mediterranean, which has a strong flow always setting into it through the straits of Gibraltar, sends back a portion of its waters into the Atlantic, by a concealed current. Contrary currents, passing along side by side, are not uncommon. In the Kattegat, a northern current flows out of the Baltic, along the coast of Sweden, while a southern one enters the Baltic along the coast of Denmark. When two opposite currents of about equal force meet one another, they sometimes, especially in narrow channels, turn upon a centre and assume a spiral form, giving rise to *eddies* or *whirlpools*. The most celebrated of

these are the *Euripus*, near the island of Eubœa, in the Grecian Archipelago; *Charybdis*, in the strait between Italy and Sicily; and the *Maelstrom*, off the coast of Norway. The most violent of them, when agitated by tides or winds, become very dangerous to navigation.

On Currents in the Atmosphere.

It does not belong to our present subject to investigate the properties and component parts of the atmosphere, but it will be proper to notice the agitations or movements which are constantly taking place in that fluid. A change in the temperature of a portion of air; an increase or a diminution of the quantity of water which it holds in a state of vapour; in short, any circumstance which causes it either to contract or to expand, destroys the equilibrium subsisting among the different parts of the atmosphere, and occasions a rush of air, that is, a *wind*, towards the spot where the balance has been destroyed.

Every one knows that the velocity and force of winds are exceedingly various; accordingly, several methods have been suggested, and instruments invented, in order to determine their amount with some degree of exactness. In the fifty-first volume of the "Philosophical Transactions," there is a table of the different velocities and forces of winds, drawn up from a considerable number of facts and experiments; the following particulars are extracted from it:—

Velocity of the Wind. Miles in an hour.	Perpendicular force on one square foot, in Avoirdupois pounds.	dec. parts.	Common Appellations of the forces of such Winds.
1		.005	.....
4 }		.079	.....
5 }		.123	.....
10		.492	.....
15		1.107	.....
30		4.429	.....
35		6.027	.....
50		12.300	.....
80		31.490	.....
100		49.200	.....

Winds may be divided into three classes—those which flow *constantly* in the same direction, those which are *periodical*, and those which are variable. It must be observed that the terms which express the direction of winds are employed in a sense quite

contrary to that in which they are used when we speak of the direction of currents in the ocean; a westerly current, for example, signifies a current flowing *towards* the west, but a westerly wind signifies a wind coming *from* that quarter.

The *permanent* winds are those which blow constantly between, and a few degrees beyond, the tropics, and are called *trade-winds*. On the north of the

* From the account which Captain Parry has given of his last voyage, it appears that there is also a great quantity of timber which has been cast by the sea upon the northern coast of Spitzbergen.

equator, their direction is from the north-east (varying at times a point or two of the compass each way); on the south of the equator, they proceed from the south-east. The origin of them is this:—the powerful heat of the torrid zone rarefies or makes lighter the air of that region; the air, in consequence of this rarefaction, rises, and to supply its place a colder atmosphere from each of the temperate zones moves towards the equator. But (as in the case of the polar currents in the ocean) these north and south winds pass from regions, where the rotatory motion of the earth's surface is less, to those where it is greater. Unable at once to acquire this new velocity, they are left behind, and instead of being north and south winds, as they would if the earth's surface did not turn round, they become *north-east* and *south-east* winds. The space included between the second and fifth degrees of north latitude, is the *internal boundary* of the two winds; and this space experiences calms, frequently interrupted, however, by violent storms. The reason why it is situated to the north of, instead of exactly at, the equator, seems to be that the northern hemisphere is warmer than the southern; for since the trade-winds are the result of the continual ascent of heated air in the equatorial parts, their internal boundary will be where the principal ascent is going on,—that is, where the annual temperature is the highest; which, on account of the above-mentioned inequality of temperature in the two hemispheres, will not be at the equator, but somewhat to the north of it. The *external limits* of the trade-winds are at a medium in about the 30th degrees of north and south latitude respectively; but each limit, as the sun approaches the neighbouring tropic, declines further from the equator. The position of the sun has an influence also on their strength and direction; for when that luminary is near the tropic of Cancer, the south-east wind becomes gradually more southerly, and stronger, and the north-east weaker, and more easterly; the effect is reversed when he gets towards the tropic of Capricorn.

The trade-winds would blow regularly round the whole globe within the distance of about 30 or 40 degrees from the equator each way, if the space within those limits were all covered

with water; but the uneven surface and unequal temperature of the land divert and derange them: it is on this account that the trade-winds are constantly experienced only over the open ocean. The larger the expanse of ocean over which they range, the more steadily they blow: thus in the Pacific they are commonly more steady than in the Atlantic ocean, and in the south than in the north Atlantic. In sailing from the Canaries to Cumana, on the north coast of South America, it is hardly ever requisite to touch the sails of the vessel. The voyage across the Pacific, from Acapulco on the west coast of Mexico, to the Philippine islands, is performed with equal facility; and if there were a channel through the isthmus of Panama, a westward passage from Europe to China would be more speedy and safe than the usual navigation thither round the Cape of Good Hope; the only interruption to the evenness of this voyage would be in the Caribbean Sea and the Gulf of Mexico, where the trade wind blows impetuously, and is sometimes interrupted by westerly winds. It would not be possible, however, to return by the same route, because in sailing east way must be made to the northward, in order to get beyond the region of the trade into that of the variable winds. Both in the Atlantic and in the Pacific Ocean, the current of the trade-winds becomes broader and more directly east in its course, as it advances from one side to the other of those extensive basins. On the west coast of Africa, owing to the rarefaction which the air undergoes over that continent, the wind is mostly turned towards the shore; from Cape Bojador to Cape Verd it is generally north-west, and thence to the island of St. Thomas, under the equator, it bends gradually first to the west and then to the south-west. Along the coasts of Chili and Peru a south wind prevails. These are two instances of the interruption which the trade-winds experience in the neighbourhood of large masses of land.

In the Indian Ocean the south-east trade-wind prevails between 28° and 10° of south latitude, from within a few degrees of the east side of Madagascar, nearly to the coast of New Holland; but from the 10th degree of south latitude to the northern shores of that ocean, the uniformity of the tropical movements of the atmosphere is de-

stroyed by the *monsoons**, which belong to the class of *periodical* winds. These blow half the year from one quarter, and the other half from the opposite direction: when they shift, variable winds and violent storms prevail for a time, which render it dangerous to put to sea. They of course suffer partial changes in particular places, owing to the form and position of the lands, and to other circumstances, but it will be sufficient to give their general limits and directions. Northward from the third degree of south latitude, a *south-west* wind blows from April to October—from October to April a *north-east*; these monsoons extend over the China sea, but here they incline more to the direction of north and south. Between the 3d and 10th degrees of south latitude, a *north-west* wind blows from October to April, and a *south-east* during the other six months of the year: the former is seldom steady in the open sea, but in December and January it sometimes extends northwards a degree or two beyond the equator. These two monsoons have the greatest strength and regularity in the Java Sea, and thence eastward towards New Guinea. The facts above exhibited may be thus summed up:—from April to October a *south-west* wind prevails north of the equator, southward of this a *south-east* wind—from October to April, a *north-east* wind north of the equator, and a *north-west* between the equator and 10° of south latitude; south of this the usual trade wind, which is in motion through the whole year.

In attempting to account for these movements of the atmosphere over the Indian Ocean, the first thing which strikes us is, that the north-east and south-east monsoons, which are found the one on the north and the other on the south side of the equator, are nothing more than the trade-winds blowing for six months, and then succeeded for the remainder of the year by winds directly opposite. It is also to be noticed that the south-west monsoon in the northern, and the north-west monsoon in the southern hemisphere, each prevails while the sun is perpendicular to their respective regions: they are, therefore, connected with the immediate presence of that luminary. If the Indian Ocean were not bounded as

it is by land on the north, the trade-winds would blow over it (at least in the central parts) as they do in the Atlantic and Pacific Oceans. But it is well known that water, owing to its transparency, is very little warmed by the sun's rays, whereas the land is powerfully heated by them; consequently, when the sun is between the equator and the tropic of Cancer, India, Siam, and the adjacent countries, become much hotter than the ocean; the air over them gets rarefied and ascends; colder air then rushes in from the Indian ocean, and a *south-west* wind is produced. When the sun, however, has crossed to the south of the equator, these countries become gradually cool, and the north-east trade-wind resumes its course. At the same time the *north-west* monsoon commences in the southern hemisphere, in consequence of the air over New Holland being rarefied by the presence of the sun.

The monsoons in the Red Sea blow in the direction of the shores; and a similar effect is observed in the Mozambique channel, between Africa and Madagascar, where these winds follow the line of the channel. On the coast of Brazil, between Cape St. Augustine and the island of St. Catharine, and in the bay of Panama, on the west of the isthmus of that name, periodical winds occur somewhat similar to the monsoons of Asia.

The *land* and *sea-breezes*, which are common on coasts and islands situated between the tropics, are another kind of periodical winds. During the day, the air, over the land, is strongly heated by the sun, and a cool breeze sets in from the sea; but in the night the atmosphere over the land gets cooled, while the sea, and consequently the air over it, retains a temperature nearly even at all times: accordingly, after sunset, a land-breeze blows off the shore. The sea-breeze generally sets in about ten in the forenoon, and lasts till six in the evening; at seven the land breeze begins, and continues till eight in the morning, when it dies away. These alternate breezes are, perhaps, felt more powerfully on the coast of Malabar than anywhere—their effect there extends to a distance of twenty leagues from the land. During summer, the *sea-breeze* is very perceptible on the coasts of the Mediterranean, and sometimes even as far north as Norway.

* From the Malay word *moossin*, which signifies a season.

We thus perceive that within the limits of from 28 to 30 degrees on each side of the equator, the movements of the atmosphere are carried on with great regularity; but beyond these limits, the winds are extremely variable and uncertain, and the observations made have not yet led to any satisfactory theory by which to explain them. It appears, however, that beyond the region of the trade-winds, the most frequent movements of the atmosphere are from the *south-west*, in the north temperate zone, and from the *north-west*, in the south temperate zone. This remark must be limited to winds blowing over the ocean and in maritime countries; because those in the interior of continents are influenced by a variety of circumstances, among which, the height and position of chains of mountains are not the least important. These south-west and north-west winds of the temperate zones are most likely occasioned in the following manner:—In the torrid zone there is a continual ascent of air, which, after rising, must spread itself to the north and south in an opposite direction to the trade-winds below: these upper currents, becoming cooled above, at last descend and mix themselves with the lower air; part of them may perhaps fall again into the trade-winds, and the remainder, pursuing its course towards the poles, occasion the north-west and south-west winds of which we have been speaking. It has also been conjectured that these winds may frequently be caused by a decomposition of the atmosphere towards the poles, from part of the air being at times converted into water.

Hurricanes have been supposed to be of electric origin. A large vacuum is suddenly created in the atmosphere, into which vacuum the surrounding air rushes with immense rapidity, sometimes from opposite points of the compass, spreading the most frightful devastation along its track, rooting up trees, and levelling houses with the ground. They are seldom experienced beyond the tropics, or nearer the equator than the 9th or 10th parallels of latitude; and they rage with the greatest fury, near the tropics, in the vicinity of land or islands, while far out in the open ocean they rarely occur. They are most common among the West India islands, near the east coast of Madagascar, the islands of Mauritius and Bourbon, in the Bay of Bengal at the changing of the monsoons, and on the coasts of China.

Whirlwinds sometimes arise from winds blowing among lofty and precipitous mountains, the form of which influences their direction, and occasions gusts to descend with a spiral or whirling motion. They are frequently, however, caused by two winds meeting each other at an angle, and then turning upon a centre. When two winds thus encounter one another, any cloud which happens to be between them is of course condensed and turned rapidly round; and all substances sufficiently light are carried up into the air by the whirling motion which ensues. The action of a whirlwind at sea occasions the curious phenomenon called a *water-spout*, which is thus described by those who have witnessed it. From a dense cloud a cone descends in the form of a trumpet with the small end downwards; at the same time, the surface of the sea under it is agitated and whirled round, the waters are separated into vapour, and ascend with a spiral motion till they unite with the cone proceeding from the cloud; frequently, however, they disperse before the junction is effected. Both columns diminish towards their point of contact, where they are not above three or four feet in diameter. In the middle of the cone forming the water-spout, there is a white transparent tube, which becomes less distinct on approaching it, and it is then discovered to be a vacant space in which none of the small particles of water ascend; and in this, as well as around the outer edges of the water-spout, large drops of rain precipitate themselves. In calm weather, water-spouts generally preserve the perpendicular in their motion; but when acted on by winds they move on obliquely—sometimes they disperse suddenly, at others they pass rapidly along the surface of the sea, and continue a quarter of an hour or more before they disappear. A notion has been entertained that they are very dangerous to shipping, owing to the descent, at the instant of their breaking, of a large body of water sufficient to sink a ship; but this does not appear to be the case, for the water descends only in the form of heavy rain. It is true, that small vessels incur a risk of being upset if they carry much sail; because sudden gusts of wind, from all points of the compass, are very common in the vicinity of water-spouts.

ON PHYSICAL CLIMATE.

Circumstances which determine its character—Mean annual Temperature—Extremes of Heat and Cold—Isothermal Lines—Temperatures of the Southern and Northern Hemispheres compared—Quantity of Evaporation and of Rain in various Latitudes—Character of the Seasons in the different Zones.

THE term *climate* is applied to the state of the air, in order to express that particular combination of temperature and moisture which exists in the atmosphere of any greater or less extent of country. The climates of different regions of the globe, and the causes which occasion their great diversity, are interesting matters of inquiry. If an uniform climate had been communicated to the whole globe, we should not have seen such wonderful variety among the animal and vegetable tribes; and many things that now raise the delight, or administer to the necessities of the human race, would have been entirely unknown. It might at first be imagined that the climate of any particular place depended solely upon the action of the sun; but, upon further consideration, we shall find that there are other circumstances to be taken into account: were it not so, any two places having the same latitude, and consequently receiving the sun's rays at the same angle, would enjoy similar climates, which is by no means the case. It is a wise ordination of Providence that the sun's action is modified in such various ways, as to produce a more equal distribution of heat over the surface of the globe than would otherwise have existed; by means of which, large regions are adapted to the residence and support of man, that would else, from extreme heat or cold, have been quite uninhabitable.

There are eight circumstances which determine physical climate:—1. The power of the sun's immediate action, which increases in proportion as we approach the equator; 2. elevation of the ground above the level of the ocean; 3. position with respect to the great seas; 4. quarter towards which the surface of the country slopes; 5. position and direction of chains of mountains; 6. nature of the soil; 7. degree of cultivation and improvement to which the country has arrived; 8. prevalent winds.

1. The amount of the immediate solar heat depends upon the position of the sun in the ecliptic, because to all places (whatever their distance from the Equator)

this position determines the length of the day, and the direction in which the sun's rays strike the earth. When the sun remains a long time above the horizon, his continued action causes a powerful accumulation of heat; the nights also being short, but little of this heat escapes during his absence. On this account it is, that even within the arctic circle the summer temperature is sometimes quite oppressive*. The direction in which the rays fall upon the earth is another important consideration; their greatest force being experienced when they are perpendicular to the surface. On the contrary, when the sun is near the horizon, his rays merely glance along the ground, and many of them, before they reach it, are absorbed and dispersed, owing to the density of the lowest stratum of the atmosphere along which they have to pass. Bouguer calculated that, out of 10,000 rays falling upon the earth's atmosphere, 8123 arrive at a given point if they come perpendicularly; 7024, if the angle of direction is 50 degrees; 2831, if it is 7 degrees, and only 5, if the direction is horizontal.

2. It is well known how the temperature of a place is influenced by the elevation of the land. In proceeding from the equator towards either of the poles, without altering our height above the level of the sea, we must travel a great distance before we find the mean annual temperature reduced even a few degrees; but, by increasing our elevation, a rapid change of temperature will be experienced, till we arrive at the point where constant frost prevails. The extreme cold which exists in the upper region of the atmosphere seems to be owing to the expansion of the air (see chap. vii. of the *Treatise on Heat*); partly, also, to the circumstance of that region being beyond the reach of the heat reflected from the surface of the earth. The decreases of heat, at equal ascents, are not altogether uniform, as they take place more rapidly in the higher parts of the atmosphere. The annexed table, abridged from one drawn up by Professor Leslie, shows that even under the equator, where the sun's direct influence is most powerful, an ascent of rather more than 15,000 feet (about 2½ miles) above the level of the sea, will bring us within the region of perpetual frost. This provision of nature of course increases considerably the number of habitable countries within the torrid zone.

* In Norway, as high as latitude 70 degrees, the thermometer has been seen to rise above 80 degrees.

Latitude.	Mean Temperature at the level of the sea.	Height of Curve of Congelation.
0	84.2 Fahr.	15,207 feet.
10	82.6	14,764
20	78.1	13,478
30	71.1	11,484
40	62.6	9001
50	53.6	6334
60	45	3818
70	38.1	1778
80	33.6	457
90	32	0

3. The effect of the sea is to *equalise* temperature, so that a maritime country is not liable to such extremes, either of heat or cold, as an inland one. The sea itself being of a very equable temperature, the winds which pass over an extent of it partake somewhat of the same character. When a *cold* wind passes over sea it receives part of the warmth of the water, the upper particles of which being thus rendered cooler, and consequently heavier than those below, descend and are succeeded by warmer particles; so that there is a *continual* tendency in the sea to temper a cold wind passing over its surface. A cold wind, blowing overland, is at first rendered warmer by the earth's surface; but this surface quickly becoming cooled, ceases to have any effect upon the wind, which, therefore, travels on with undiminished rigour. Again, a *warm* wind, in passing over sea, is cooled by the agitation which it produces bringing up cooler water from below, as well as by the constant evaporation which it occasions; the surface of the water also cannot, as that of land, be powerfully heated by the sun's rays, because it affords them a free passage, and therefore it cannot communicate heat to the atmosphere in the degree which the land does. From these circumstances it results, that, though a place situated inland, and another upon a coast may have the same mean annual temperature, the range of the thermometer at each will be very different, the summers of the latter will be cooler, and the winters milder than those of the former. It is from this cause that islands are so much more temperate than continents. It follows, too, that countries in our hemisphere will be rendered warmer by having large tracts of land to the south and sea to the north, and cooler when the relative position of these two is reversed. This fact is exemplified by a comparison of the climate of India with that of Africa north of the equator, the heats of the former country being much more supportable than those of the latter. Not only the temperature of a wind, but also its degree of moisture, depends upon the nature

of the surface over which it passes. A wind coming up from the ocean is loaded with vapours, but one sweeping over an extent of land is rendered dry and parching. This explains to us why, in our own island, a south-west and an easterly wind are so opposite in character.

4. The aspect of a country has an influence upon its climate, for this reason, that the angle at which the sun's rays strike the ground, and consequently the power of those rays in heating it, varies with the exposure of the soil relatively to that luminary. When the sun is elevated on the meridian 45 degrees above the horizon, his rays fall *perpendicularly* on the side of a hill facing the south at an equal angle, while the plain below receives them at an *angle of 45 degrees*. Supposing the north side of the hill to have a similar slope, the rays would run *parallel* to its surface; and their effect be very trifling, but if the declivity were still greater, the whole surface would be in the shade. This, though an extreme case, serves to show why temperature varies with the inclination of the earth's surface. Since the warmest part of the day is not when the sun is on the meridian, but, owing to the accumulation of the heat, two or three hours afterwards, it follows that, in our hemisphere, a south-south-west or south-western aspect is the warmest, and a north-north-east, or north-eastern, the coldest, if no local circumstances exist to make it otherwise. The effect of aspect is, of course, most strikingly seen in regions covered with high mountains. In the Vallais in Switzerland, the Alps are on one side covered with ice, while vineyards and orchards flourish on the other.

5. Mountains affect a climate in more ways than one. They attract the vapours in the atmosphere, and causing them to condense, give rise to those violent rains which are often experienced in the neighbourhood of lofty ranges. They also afford shelter from winds. In narrow valleys, the sides of which in summer strongly reflect the sun's rays, this shelter sometimes renders the heat very injurious. One reason why the central and southern parts of European Russia are exposed to greater cold than their latitude and inclination southward would lead us to expect, is the absence of any chain of mountains to protect them from the full influence of the winds blowing from the White Sea and the Ural Mountains. The inhospitable climate of Siberia arises from its descent towards the north exposing it to the winds of the

Frozen Ocean, while at the same time the vast mountainous chains that cross central Asia, intercept the southern winds, whose access would tend to mitigate the rigour of the atmosphere.

6. It is evident that the nature of the soil must very materially operate upon climate. One soil acquires heat, keeps its acquired heat much longer, or reflects it more readily, than another. One, which from its porous character allows the rain descending upon it to pass freely into the earth, will emit much fewer exhalations than one which retains the waters near the surface. Thus clayey or marshy grounds lower the temperature, and especially in hot and humid climates, affect the atmosphere in a manner pernicious to health; on the other hand, those which are light, stony, or calcareous, tend to make the atmosphere salubrious. The great cold, and the unwholesome air that prevail in the Russian governments of Astracan and Orenburg, lying to the north of the Caspian Sea, are attributed partly to the saline nature of the soil; and it is well known that the arid tracts of sand in Africa and Arabia, conduce not a little to the excess of heat under which those countries labour.

7. Without cultivation, few climates would be healthy or agreeable. In countries to which the labours of civilized man have never been extended, the rivers, spreading themselves over the low grounds, form pestilential marshes, and forests, thickets, and weeds are so numerous and impenetrable, as to prevent the earth from receiving the beneficial influence of the sun's rays. The air, from these causes, is constantly filled with noxious exhalations. But the efforts of the human race, conducted with skill and perseverance, produce a surprising change: marshes are drained; rivers embanked; the soil broken up by the plough is exposed to the sun and wind, and the clearing away of the forests raises the temperature, and allows a freer circulation to the atmosphere. There is little doubt that many parts of Europe enjoy a milder climate now than they did in the time of the Romans, or even at periods much more recent. Several districts in North America have experienced, as the country has become more widely settled, a similar improvement of climate. The destruction of forests may, however, be carried to a pernicious extent, either by depriving a country of shelter from particular winds, or (especially in hot climates) by lessening too much the

quantity of moisture; it being well known that there is a great evaporation from the leaves of vegetables. The sultry atmosphere and dreadful droughts of the Cape de Verde islands are owing to the destruction of the forests; and Greece, Italy, and other countries are said to have been deteriorated in climate from the same cause. It is attributed to this also that the southern part of Iceland is more accessible than formerly to the cold which proceeds from the Arctic Ocean.

8. The combined influence of the several causes of physical climate which we have been considering will be variously modified by the *prevailing winds* of a country. This is obvious enough, because we know that the character of a wind depends upon the quarter whence it comes, and the surface over which it passes. Great Britain, for example, would in a great measure lose its insular climate, if its prevailing winds came across the continent, instead of from the Atlantic Ocean.

Notwithstanding the several circumstances which we have thus pointed out as influencing climate, and which occasion numerous local irregularities, the temperature, with these exceptions, becomes gradually lower as we pass from the equator towards either of the poles. By this is not to be understood the temperature of any particular day, or even season, but the *mean annual temperature*, which is obtained by adding together the temperatures of all the months*.

* The temperature of each month is the average of all the daily temperatures in the month, and the daily temperature is the average of several observations made at stated periods, every hour or half hour, for instance, each day (24 hours). It is evident that such frequent observations would be very troublesome, and shorter methods of discovering the mean annual temperature of a place have therefore been sought after. Rules have been laid down for calculating what this is under different parallels of latitude, and the results no doubt approach very near to the truth; but it would obviously be incorrect to apply these rules to any particular place, because we should be uncertain how the climate of that place was affected by local circumstances. The best method is to ascertain at what period in each day (taking one day with another) the thermometer stands at its mean height for the day; and when this has been ascertained, one observation each day, at that period, will be sufficient. In this country it would appear that the time at which the thermometer shows the mean heat for the day, is about a quarter or half past eight in the morning. Another method of discovering the mean annual temperature at any place, is to observe the height of the thermometer in cavities at some depth below the earth's surface, it being found that this height nearly corresponds with the mean annual height in the air above. M. Lacroix, in his work on Physical Geography, states that in the caves below the Observatory at Paris, (lat. 49°) about 85 feet below the surface, Fahrenheit's thermometer constantly stands between 52° and 54°, scarcely ever varying two degrees, while above, the difference of temperature between summer and winter sometimes exceeds 90°. In the salt mines at

and dividing the sum by the number of months in the year; so that the mean annual temperature expresses that height at which the thermometer would stand at any place, if we could suppose it perfectly stationary throughout the whole year. It is not sufficient, however, to take one year only, but a series of at least ten or fifteen years, from the *mean* result of which series a conclusion nearly accurate may be drawn. Though the temperature of a place is continually varying, and though the changes occur frequently in the most sudden manner, it never differs more than a certain number of degrees either way from its mean state; and when it has reached either extreme, a reaction may shortly be expected. In the torrid zone any excessive accumulation of heat is prevented by the constant blowing of the trade-winds from cooler regions; and in the frigid zones the tendency to great extremes which arises from the continued presence of the sun in summer, and his long absence in winter, is counteracted by the circulation of the atmosphere, and by the circumstance that the fields of ice, in melting, absorb large quantities of heat, while on the other hand warmth is given out when the surface of the ocean is being frozen over.—(See chap. ix. of the *Treatise on Heat*.)

The extremes of temperature which have been witnessed in different parts of the globe are, nevertheless, very considerable. In New South Wales, Fahrenheit's thermometer sometimes rises to 100 degrees and upwards; at Pekin, in China, it has been seen at 110°, and at different places in India at 110°, and even 115°. Major Denham, in his late travels in Africa, observed it more than once at 113°; and at Belbeis, in Egypt, it is said to have risen, under the influence of the hot wind from the desert, to 125°.* These heights are intended to express the degree of heat in the *shade*. The accuracy of the observations depends upon the circumstances under which they were made, since it is requisite that the thermometer should be in a situation freely

exposed to the outer air, and also where there are no surfaces immediately near to reflect the sun's rays. The most extreme cold experienced is in the northern parts of Asia and America. In Siberia, as far south as the 58th degree of latitude, M. Pallas observed the freezing of mercury*. The same phenomenon is by no means unusual at Quebec. At Hudson's Bay the spirit thermometer has sunk to —50°, and at Melville island, (N. lat. 74½°,) where Captain Parry wintered in his first north-western expedition, it fell, on the 15th February, 1820, to 55 degrees below zero.

A treatise upon *isothermal*† lines, published some years ago by M. Humboldt, gives several curious results drawn from various observations upon temperature made by himself and others. A few of these it will be proper to notice here, because they illustrate, in a striking manner, the fact upon which we have already remarked, that the climates of places do not depend solely upon the direct action of the sun. If it were so, all places having the same latitude would experience the same mean annual temperature. It had long been known that this was not the case, especially on comparing Europe with America; but M. Humboldt's statements will enable us to form some idea of the amount of the difference. According to that philosopher, the isothermal line which indicates the temperature of 32 degrees (the freezing point of water) passes between Ulea, in Lapland (lat. 66°) and Table Bay, on the coast of Labrador, in North America, lat. 54°. The isothermal line of 41 degrees passes near Stockholm, lat. 59½°, and St. George's Bay, Newfoundland, lat. 48°. The line of 50 degrees runs through the Netherlands, lat. 51°, and near Boston, in the United States, lat. 42½°; that of 59 between Rome and Florence, lat. 43°, and near Raleigh, in North Carolina, lat. 36°. Taking similar latitudes, the following are the differences of temperature between the west of Europe and the east of North America:—

Latitude.	Mean temperature in the West of Europe.	Mean temperature in the East of America.	Difference.
	°	°	
30	70.1	66.8	3.3
40	63.1	54.5	8.6
50	50.8	37.9	12.9
60	40	24	16

* This takes place when the mercury has sunk to 39 or 40 degrees below zero.

† This is derived from two Greek words, and signifies *equal heat or temperature*. An isothermal line, therefore, is a line drawn over places which have the *same temperature* (annual, unless otherwise expressed.)

Wieliczka, in Poland (lat. 50°), from the depth of 320 to that of 745 feet, the thermometer stands at about 50°. At Cairo, in Egypt, (lat. 30°), at the bottom of Joseph's well (210 feet deep), it stands at 70°; in the mines of Mexico (lat. 20°), 1650 feet below the surface, it stands at 74½°. In these heights we discern how the temperature increases on approaching the equator.

* When the thermometer is raised to such an extraordinary height as this, it is probably the effect produced by very fine particles of sand which are carried along by the atmosphere. Humboldt, in the arid plains of South America, has, during a *wind of sand*, seen it at 114½ degrees nearly; while in Fezzan, in the North of Africa, it has risen, doubtless from the cause just noticed, to 125.6 degrees.

From the annexed table, there appears to be nearly as much difference between the mean temperatures of the eastern and western parts of the old continent as between those of the opposite shores of Europe and America:—

Places.	Latitude.	Longitude.	Mean temperature.
St. Maloes .	48° 39' N.	1° 57' W.	54.50
Amsterdam .	52 22	4 40 E.	53.4
Copenhagen .	55 41	12 30	45.7
Upsala . . .	59 51	17 48	41.9
Naples . . .	40 50	14 10	63.5
Vienna . . .	48 11	16 22	50.5
Warsaw . . .	52 14	21 10	48.6
Moscow . . .	55 45	37 31	40.1
St. Petersburg	59 56	30 25	38.8
Pekin (China)	39 54	116 28	54.9

M. Humboldt, after tracing the isothermal lines across America, concludes that, in California and thence northward along the western side of that continent, the temperature is nearly the same as in similar latitudes on the western side of Europe. "Europe," he then observes, "may be considered altogether as the western part of a great continent, and, therefore, as being subject to all the influence which causes the western sides of all continents to be warmer than the

eastern. The same difference which has been observed between the two shores of the Atlantic, exists between the two opposite coasts of the Pacific. In the north of China, the extremes of the seasons are much more felt than in the same latitudes in New California, and at the mouth of the Columbia. On the eastern side of North America, the same extremes occur as in China. New York has the summer of Rome and the winter of Copenhagen. Quebec has the summer of Paris and the winter of Petersburg. In the same manner, at Pekin, which has the mean temperature of Britain, the heat of summer is greater than at Cairo, and the cold of winter as severe as at Upsal. This analogy between the eastern coasts of Asia and America sufficiently proves that the inequality of the seasons depends upon the prolongation and enlargement of the continents towards the pole, and upon the frequency of the north-west winds, and not upon the proximity of any elevated tracts of country." The following table illustrates the preceding remarks:—

Places.	Latitude, North.	Mean annual temperature.	Mean temperature.					Difference in the heat of these months.	
			Winter.	Spring.	Summer.	Autumn.	Coldest M.	Hottest M.	
Philadelphia	39.56	54.86	33.98	53.06	75.20	56.32	32.70	77.00	44.30
Pekin	39.54	54.86	26.42	56.30	82.58	54.32	24.62	84.38	59.76
Nantes .	47.13	54.68	40.28	54.50	68.72	55.58	39.02	70.52	31.50
Rome .	41.53	60.44	45.86	57.74	75.20	62.78	42.08	77.00	34.92
Paris .	48.50	51.44	37.92	49.64	64.40	51.26	35.96	67.46	31.50
Quebec	46.47	41.72	14.18	38.84	68.00	46.04	12.74	73.40	60.66
Upsala .	59.51	41.9	24.98	39.38	60.20	42.80	24.26	61.88	37.62

The fact that places which have the same annual temperature experience very different seasons, is clearly exhibited in this comparison. From Humboldt's inquiries, it appears that the lines which mark the winter temperature deviate much more from the parallels of latitude than those which express the mean annual temperature. In Europe the latitudes of two places which have the same annual heat, never differ more than 8° or 9°: but the difference of latitude in those having the same winter temperature is sometimes no less than 18° or 19°. The winter of Scotland is as mild as that of Milan. With respect to summer, the same heat takes place at Moscow and at the mouth of the Loire, though the former is nearly 9 degrees north of the latter. Ireland is remarkable for mild winters and cold summers; the mean temperature in Hungary for the month of August is 71°·6, while in Dublin it is no more than 60°·8.

It is generally believed that, beyond a

certain distance from the equator, the temperature of the southern is lower than that of the northern hemisphere. In speaking of the temperature of the ocean, we have already observed that ice is fallen in with much sooner in sailing towards the south, than it is in approaching the north pole. Humboldt says, that near the equator, and indeed through the whole of the torrid zone, the temperature of the two hemispheres appears to be the same; but that the difference begins to be felt in the Atlantic about 22° of latitude; the mean temperatures of Rio Janeiro and Havannah, places at about an equal distance from the equator (23 degrees) being in the latter instance 76°·4, and in the former only 74°·5.—The southern climates generally differ from the northern with respect to the distribution of temperature through the different parts of the year. In the southern hemisphere, under the isothermal lines of 45° and 50°, there are summers which, in our hemisphere, belong to the

lines $35\frac{1}{2}^{\circ}$ and 41° . There is no accurate information as to the mean temperature of any place beyond 50° of south latitude; but there is every reason to suppose that it differs considerably from that of places in the same degree of north latitude.

The same writer, in the second volume of his *Personal Narrative*, presents the following comparison of the temperature of the air in both hemispheres. The observations employed in drawing it up were all made at sea, except those from which the mean temperature for S. lat. 34° was deduced, which were made at the Cape of Good Hope.

Latitude.	Corresponding Months.	Mean Temperature of the Months.	
		Southern Hemisphere.	Northern Do.
0°—15°	December } Summer	82.4°	
	June }		83.3
18	October } Autumn	81.5	79.7
	April }		
2—26	January } Winter	72.5	66.74
	July }		
"	September } Autumn	69.44	68.9
	March }		
34	December } Winter	56.84	59.72
	June }		
"	February } Winter	62.24	62.6
	August }		
43	July } Summer	59.36	64.76
	January }		
48	June } Summer	44.6	63.86
	December }		
58	July } Summer	43.16	56.3
	January }		

The coldness of the southern hemisphere has frequently been attributed to a circumstance quite inadequate to explain it, namely, that of the sun being a shorter time (by $7\frac{1}{4}$ days), on the south, than on the north side of the equator. A much greater influence than we can assign to this cause, must be ascribed to the very large proportion which the ocean bears to the land of the southern hemisphere, in consequence of which its climate differs from that of the northern, in the same way as an insular climate differs from a continental one. But even this is not altogether a sufficient explanation, and there still remains a circumstance that deserves attention. The absence from the south polar regions of any great extent of land, and the manner in which the South American continent terminates, permit the grand current of the antarctic ocean to flow freely all round that part of the globe, towards the equator. This current, being unchecked till it is lost in the westerly movement of the ocean, carries along with it the circumpolar ice into very low latitudes; and the continual

absorption of heat by the melting of the ice, as it gradually advances into warmer parts, keeps the air at a lower temperature than in the northern hemisphere, where circumstances are not favourable to the passage of the polar ice out of the regions in which it is formed. Beyond the limit, however, at which the ice disappears, but little effect will be produced on the temperature by its melting, and we accordingly find that within the torrid zone, the warmth of one hemisphere is the same as that of the other, and that as far as the 35th, or even 40th degrees of latitude, there is no important difference.

The question has sometimes been agitated, whether the general temperature of the globe suffers any change. Some have gone so far as to imagine that it gradually diminishes, others have been of opinion that it receives an augmentation. Neither of these theories has very solid foundation; it is scarcely more than a century since the thermometer was rendered a correct measure of heat, and the number of observations made with it in different parts of the world is by no means sufficient to form a basis for such sweeping conclusions. If we possessed a regular series of observations taken in various countries, and extending through three or four centuries, we should most likely be enabled to discover a mean state both of temperature and moisture to which the atmosphere continually returns; and there is no doubt that if we could obtain a clear insight into the complex machinery which regulates the seasons, we should behold the same beautiful harmony, and the same system of compensation for temporary and apparent irregularities, which we are able to discern in the movements of the heavenly bodies. Independent, however, of any question as to the general temperature of the globe, a notion has been entertained that throughout Europe, a more mild and genial climate formerly prevailed: but such historical evidence as can be collected tends to prove exactly the reverse; and that the climate, as might be supposed, has, generally speaking, improved with the advance of cultivation. A discussion of this subject will be found in the first article of the *Edinburgh Review*, No. LIX., published in June, 1818. That article contains a list of the remarkable seasons which have taken place in Europe for several centuries past, and from the view there given we may venture to conclude, that severe cold is of much rarer occurrence than it was in former ages.

Having thus noticed the subject of temperature, it will be proper to advert to the amount of moisture which the atmosphere contains in different parts of the globe. In the course of this inquiry we shall not make use of the results given by the hygrometer*, because that instrument is neither so well known, nor brought to such a correct standard as the thermometer, but merely give the quantity of evaporation, and the depth of rain that has been observed to fall at several places upon the earth's surface.

Other things being equal, evaporation is the more abundant, the greater the warmth of the air *above* that of the evaporating body, and least of all when their temperature is the same. Neither does much take place whenever the atmosphere is more than fifteen degrees colder than the surface upon which it acts. Winds powerfully promote evaporation, because they bring the air into continual, as well as into closer and more violent contact with the surface acted upon, and also, in the case of liquids, increase, by the agitation which they occasion, the number of points of contact between the atmosphere and the liquid. It must be familiar to every person that the same quantity of water spread over a larger space, is dried up in a less period.

In the temperate zone, with a mean temperature of $52\frac{1}{4}$ degrees, the annual evaporation has been found to be between 36 and 37 inches. At Cumana, on the coast of South America (N. lat. $10\frac{1}{2}$), with a mean temperature of 81.86 degrees, it was ascertained to be more than 100 inches in the course of the year; at Guadaloupe, in the West Indies, it has been observed to amount to 97 inches. The degree of evaporation very much depends upon the difference (greater or less) between the quantity of vapour which the surrounding air is able to contain *when saturated*, and the quantity which it actually contains. M. Humboldt, from observations made in the passage across the Atlantic, found that in the torrid zone the quantity of vapour contained in the air, is much nearer to the point of saturation than in the temperate zone. The evaporation within the tropics is, on this account, less than might have been supposed from the increase of the temperature.

The quantity of rain falling upon the earth at any place is determined by observing the height of the water collected in a pluviometer or rain-gauge. When an

inch is said to have fallen, it implies that the rain which has descended on any given surface would have acquired that depth, supposing none of it to have been absorbed by the ground, and that it received no addition by means of water flowing from the parts adjacent to that surface. The average yearly quantity of rain is greatest within the tropics; and it seems, in general, to diminish, the farther we recede from the equator. In the torrid zone it amounts, at a medium, to 100 or 110 inches, while in the north temperate zone it cannot be stated at more than 30 or 35 inches. These quantities are very differently distributed throughout the year in the two zones: the number of rainy days towards the equator is, in the majority of places, *less* than in the higher latitudes, and the rain consequently descends there in the most violent torrents: at Bombay, 16 inches have been collected in a gauge in the space of twenty-four hours. In general, much more rain falls in mountainous countries than in plains, and in countries covered with extensive forests than in those where wood is less abundant. Annexed, is a table of the annual quantities which have been observed at several places.

Places.	Latitude.	Mean annual quant. of rain.
Island of St. Domingo	19° N.	120 in.
Ditto Grenada	12	112
Calcutta	$22\frac{1}{2}$	70 to 75
Rome	42	36
Paris	49	21
London	$51\frac{1}{2}$	23 or 24
Liverpool	$53\frac{1}{2}$	34
Kendal, Westmoreland	$54\frac{1}{2}$	60
St. Petersburg	60	16
Upsal	60	16

The average annual fall of rain at Bombay in the ten years 1817 to 1826, was 78.1 inches; of those years the most rainy was in 1822, in the course of which nearly 113 inches fell: whereas in 1824, a season of extreme drought and famine, the supply did not much exceed 34 inches. At Arracan, in 1825, nearly 60 inches were registered in the month of July, and above 43 in August; from which we may conclude, that the whole quantity within the year was at least 150 inches. It would seem, however, that at some places within the tropics the fall is much more copious even than this. Humboldt, on the authority of others, mentions two instances of such excessive rain as almost to induce a suspicion of the correctness of the observations. He informs us that a M. Pereira Lago, by means of a pluviometer, found the quantity of rain, in the year 1821, at San Luis do Maranhao, in Brazil (S. lat. $2\frac{1}{2}$), to be $280\frac{3}{4}$

* Derived from the Greek, and signifies *measure of moisture*.

inches; and also, that Captain Roussin relates the fact of more than 160 inches having fallen at Cayenne in the single month of February.—(See vol. vi. of the *Translation of Humboldt's Personal Narrative*, Note to p. 276.)—At the same time, these accounts appear less surprising when we reflect, that, over some of the immense forests of Guyana there is wet weather almost the whole year, and that incessant rains of four or five months are no uncommon occurrence.

It must not, however, be imagined that the climate of all hot countries is characterised by such abundant rains; for there are many which, from one year to another, are either almost or entirely destitute of rain. This is the case along an extent of several hundred miles of the coast of Peru, in Egypt and many other parts of Africa, and also in the desert tracts of Arabia. At Cumana, on the North coast of South America, the annual quantity of rain is scarcely 8 inches; and there are other places on the shores of that continent where none falls for several years, but where, nevertheless, vegetation is exceedingly strong, owing to the humidity of the atmosphere.

It is well known that the air becomes drier and less loaded with vapours, the higher we ascend. On looking from the top of the Andes towards the Pacific Ocean, a haziness is often seen, spread uniformly over the surface of the waters to the height of 9500 or 11,500 feet; and this, too, in a season when the atmosphere, beheld from the coast and at sea, appears quite pure and transparent. This decrease of vapour in the upper regions of the atmosphere, combined with the rarefaction of the air, is the cause of the beautiful deep tint which the sky assumes when viewed from the summits of lofty mountains. Small white fleecy clouds are sometimes, however, seen floating above the Andes at the height of 25,000 feet; from which we may judge, that even on the tops of that range the colour of the sky is not so pure as it would appear, if it were possible for an observer to attain a further elevation. In passing also from the temperate to the torrid zone, the azure hue of the sky is found to augment progressively: the transparency of climate which is so much admired in Italy and Greece is far surpassed by that which invests the plains of Quito and Peru, or the fertile islands of the Pacific Ocean.

In the torrid zone, the temperature ranges within comparatively small limits; and the various phenomena of the atmo-

sphere occur, from one year to another, with a regular and uniform succession unknown in this part of the world. Two seasons, the *dry* and the *rainy*, divide the year. The latter depends upon the presence of the sun; countries north of the line have their wet season when that luminary is in the northern half of the ecliptic, that is, from April to October; while with southern countries it is exactly the reverse. We cannot fail to be struck with this admirable arrangement for affording shelter from the perpendicular rays of the sun, the unrestrained influence of which would be quite insupportable. Humboldt has given us an account of the atmospheric appearances which succeed each other in that part of South America lying between 4° and 10° of north latitude, and to the east of that branch of the Andes which terminates on the Atlantic side of the lake of Maracaybo. Nothing can surpass the clearness of the atmosphere from the month of December to that of January. The sky is then constantly without clouds; and if one should appear, it is sufficient to excite the whole attention of the inhabitants. The breeze from the east and the east-north-east blows with violence. The immense plains (called *Llanos*), which in the rainy season display a beautiful verdure, gradually assume the aspect of a desert; the grass is reduced to powder, the earth cracks; and the alligator and the large serpents remain buried in the dried mud till the first showers of the year awaken them from their lethargy. About the end of February, and the beginning of March, the blue of the sky becomes less intense, the hygrometer indicates greater humidity, and the stars, veiled at times by a slight vapour, lose the steady and planetary light which before distinguished them. The breeze at this period becomes less strong and regular, and is often interrupted by dead calms. The clouds accumulate toward the south-south-east, appearing like distant mountains, with strongly-marked outlines; and from time to time they detach themselves from the horizon, and traverse the vault of the sky with a rapidity that little corresponds with the feebleness of the wind below. At the end of March, the southern region of the atmosphere is illuminated by gleams of lightning; and the breeze then passes frequently, and for several hours together, to the west and south-west. This is a certain sign of the approach of the rainy season, which begins at the Oroonoko about the end of April. The sky be-

comes obscured, the azure disappears, and a grey tint is spread uniformly over it;—at the same time the heat progressively increases; and soon, dense vapours cover the heavens from one end to the other. The plaintive cry of the howling monkeys begins to be heard before the rising of the sun. The atmosphere is at length convulsed by frequent thunder-storms, the rains descend in torrents, and the rivers, rising rapidly above their banks, overspread the plains with extensive inundations.

The occurrence of these periodical rains is capable of being explained in a very simple manner. We have remarked that they always take place in that half of the torrid zone to which the sun is vertical at the time; and that in the northern half they are preceded by the gradual subsidence of the north-easterly breezes, which are followed by calms, interrupted frequently by stormy winds from the south-east and south-west. While the north-east breeze blows with all its strength, it prevents the atmosphere over the equinoctial lands and seas north of the equator from being saturated with moisture. The hot and moist air rises above, and the north-east current continually supplies its place with colder and drier strata. In this way, the humidity of the northern torrid zone, instead of being accumulated and forming condensed vapours, ascends, and flows towards the temperate regions; and, accordingly, while the north-east breeze retains its force, which is when the sun is present in the southern signs, the sky is constantly serene. In proportion, however, as the sun passes over the equator towards the tropic of Cancer, the north-east breeze softens, and by degrees entirely ceases, because the difference in temperature between the northern temperate and the torrid zone is then at its least. The breeze having ceased, the humid air is no longer replaced by drier air from the north; and, under the powerful action of a vertical sun, the vapours rapidly accumulate, till they at length descend in violent rains. This state of things continues till the sun re-enters the southern signs; then is the commencement of cold in the temperate zone, and the current from the north sets in again,—because the difference between the warmth of the equinoctial and that of the temperate regions daily increases. By this current the air of the northern torrid zone is renewed; the rains cease, the vapours disappear, and the sky resumes its clearness and serenity of aspect,

These remarks are principally intended to refer to the seasons in the northern part of South America; but, with certain exceptions, they may very nearly be applied to those of the whole torrid zone—of course bearing in mind that, south of the equator, the rainy season is from October to April, and that the *south-east* corresponds to the *north-east* breeze of northern countries. The period of commencement of the rains is not exactly the same everywhere; and there are places where great anomalies are occasioned by the existence of chains of mountains which attract the vapours and alter the direction of the winds. In the West Indies, and also on some parts of the American continent, *two* wet seasons are distinguished; one of these, however, is of much shorter duration, and has much lighter rains than the other. In India, the rains are brought on by the south-west monsoon.

The four seasons which we distinguish in this country are known only in the temperate zones. Their succession is the most regular and perceptible from the 40th to the 60th degree of latitude; but in this we speak of Europe only, for both in America and Asia a much shorter interval separates the heat of summer from the cold of winter. That part of the northern temperate zone, which lies between the tropic of Cancer, and latitude 35°, has, in many places, a climate resembling that of regions within the tropics. In Europe, even as high as the 40th degree, the frost in the plains is neither intense nor long-continued; the trees are not stripped of their foliage above two months in the year, and although snow sometimes falls at the level of the sea, even in the 37th degree (at Malaga, for example), it is an occurrence very unusual.

From the 60th degree of latitude to the pole, only two seasons take place. A severe and protracted winter is succeeded immediately by the warmth of summer. The rays of the sun, notwithstanding the obliquity of their direction, produce powerful effects, because the great length of the days is favourable to the accumulation of heat. Even in very high latitudes, the tar on the ship's sides is sometimes melted and made to run down by the sun's action. In the north of Europe the snow is generally dissolved in three or four days, and the flowers almost immediately begin to blow. The breaking up of the thick field of ice which is annually spread over the surface of the arctic ocean, commences in the month,

of June, and at this season dense fogs are very common, owing to the surface of the water being colder than the air lying over it. These at length disperse, and a short interval of fine weather ensues; but, before the close of August, the approaches of winter are perceived; snow falls; and, as the temperature of the atmosphere declines more rapidly than that of the sea, fogs, called the *frost-smoke*, again arise, which disappear only when the ice has begun to extend itself over the clear spaces of the ocean. It is worthy of remark that, even in the circumpolar regions, the west of Europe still maintains its superiority of temperature over the east of North America; for the sea off North Cape in Norway, though in the 72d degree of latitude, is always open, whereas several degrees further south, off the shores of America, it is annually frozen over.

*On the Distribution of Vegetables—
Vegetation of the different Zones—
Primitive centres of Vegetation.*

THE subject of physical climate is in itself highly interesting; but it becomes still more so when we extend our view, and consider its effects upon the numerous animal and vegetable tribes which are dispersed over the earth. This dispersion has not been the result of a blind and unmeaning chance; the same wisdom which called them into such beautiful and various existence, has fixed laws for their distribution over the surface of the globe. To these laws (without entering into details which belong to botany and zoology) we shall now direct our attention.

The wide extension of vegetable life furnishes one of the most striking examples of the productive power of nature. Every climate, as we pass from the equator to the pole, or from the plains just raised above the level of the ocean to the summits which are covered with eternal snow, has its peculiar vegetation. Countries, the most inhospitable and locked up in frost nearly all the year, are not entirely destitute of it. On Melville Island (N. lat. 75°), where the duration of winter is nine or ten months, and the mean annual temperature only two degrees above zero, there are places which produce, in abundance, moss, lichen, grass, saxifrage, poppy, the dwarf willow, and the sorrel which is so valuable for its antiscorbutic qualities: the expedition under Captain Parry observed, in a sheltered spot of this island, a ranunculus in full flower in the second week of June.

It is thought that even perpetual snow may be the abode of a species of vegetation; for Saussure discovered in it a reddish dust, and a red colouring matter has frequently been observed in snow by navigators in the arctic regions*.

The absence of light does not altogether prevent vegetable existence; caverns and mines produce certain plants, principally those of the cryptogamous class. In the cave of Caripe, situated to the south-east of Cumana in South America, the seeds, which are carried in by the nocturnal birds called Guacharoes, spring up at the distance of several hundred yards from the mouth of the grotto, wherever they can find mould to fix in. Blanched stalks, with some half-formed leaves, rise to the height of more than two feet; but M. Humboldt, who observed them, could not ascertain the species of these plants, their form and colour being so much changed by the absence of light. Vast fields of marine plants spring from the depths of the ocean, especially towards and within the tropics; the vine-leaved fucus vegetates at the depth of 200 feet, and, notwithstanding, has leaves as green as those of grass. In the Atlantic, between the 23d and the 35th degrees of latitude, and in the 29th and 30th of longitude, the fuci float on the surface in such numbers as to give the appearance of an immense inundated meadow. It is supposed, by many botanists, that they grow at the bottom of the sea, and float only in their ripened state, when torn off by the motion of the waves or otherwise.

Extreme heat is not destructive of vegetation, provided that it be accompanied by humidity. Plants grow, not only on the borders of hot springs, but even in the midst of waters which we should have supposed to be quite unsuited to their

* Captain Parry, in his Narrative of the attempt made in the year 1827 to reach the North Pole, mentions some striking examples of this appearance.—“In the course of this day's journey, we met with a quantity of snow, tinged, to the depth of several inches, with some red colouring matter. This circumstance recalled to our recollection our having frequently before, in the course of this journey, remarked that the loaded sledges, in passing over hard snow, left upon it a light rose-coloured tint, which, at the time, we attributed to the colouring matter being pressed out of the birch of which they were made. To-day, however, we observed that the runners of the boats, and even our own footsteps, exhibited the same appearance; and on watching it more narrowly afterwards, we found the same effect to be produced, in a greater or less degree, by heavy pressure, on almost all the ice over which we passed, though a magnifying glass could detect nothing to give it this tinge. The colour of the red snow, which occurred only in two or three spots, appeared somewhat different from this, being rather of a salmon than a rose colour, but both were so striking as to be the subject of constant remark.” This colouring substance has generally been thought to belong to the order *Algæ*.

existence. Examples of this sort occur in Iceland and many other countries. Even sulphureous exhalations are not fatal to vegetation: it is reported that the interior of the crater of Vesuvius, after a long period of repose, was in 1611 covered with shrubs. The greatest obstacle to it is the absence of moisture; those sandy tracts where rain seldom or never falls, and where the soil is constantly being shifted by the winds, exhibit a hopeless sterility. The verdure of the *oases*, or islands of vegetation, scattered over some parts of the African desert, is maintained by springs which rise up to the surface of the ground. The chemical nature of the soil influences the size and vigour of plants rather than sets limits to their cultivation. Common salt, however, dissolved, and scattered over the earth in large quantities, almost entirely prevents their growth. The fusion which lava undergoes is probably the reason why the progress of vegetation on its surface is so long retarded; whereas, from the ashes thrown out by volcanoes, the most abundant crops are raised.

The scale of atmospherical heat is that which ordinarily determines the character and progress of vegetation. Hence, under the fierce climate of the torrid zone, we need only ascend lofty mountains, to a certain height, in order to behold the trees, fruits, and flowers of the temperate zone; while still higher are found those of the frigid zone. The low vallies of the Andes, towards the equator, are adorned with bananas and palm-trees, while the elevated parts of the chain produce oaks, firs, and several other tribes common to the north of Europe. Near the equator, the oak grows at an elevation of 9200 feet above the sea, and never descends lower than one of 5500 feet; but, in the latitude of Mexico, it is seen as low as 2600 feet. From the height of about 15,000 feet, to the boundary of perpetual congelation, lichens are the only plants visible. Similar gradations, on a smaller scale, are observed among the Alps; on ascending which, chesnuts, beeches, oaks, and pines occur in succession, the last gradually becoming stunted till they disappear not far from the border of perpetual snow. The vegetation which covers the sides of mountains may be divided into distinct zones or bands, each zone containing its peculiar tribes. On the volcano of Teneriffe, one of the Canary Islands (N. lat. $28\frac{1}{2}^{\circ}$), as many as five of these zones are distinguished*:—(1) the

region of *vines*; (2) of *laurels*; (3) of *pin*es; (4) of the *retama* (an alpine broom); and (5) the region of *grasses*. These zones are arranged in stages, one above another, and occupy, on the declivity of the Peak, a perpendicular height of 11,200 feet.

In the equinoctial region where, in respect of warmth, the seasons differ little from each other, the geographical distribution of plants is regulated almost entirely by the mean temperature of the whole year; but in the temperate zone this distribution depends not so much upon the mean temperature of the year as upon that of the summer season. In Lapland, there are fine forests on the continent at Enontekies, where the mean annual temperature is only 27 degrees, while on the island of Mageroe, where it is more than 32 degrees, only a few scanty shrubs are to be seen. The more vigorous vegetation of Enontekies is the effect of a warmer summer; the mean temperature of July being there $59\frac{1}{2}^{\circ}$; whereas, at the isle of Mageroe, it is only $46\frac{3}{4}^{\circ}$. Some plants in summer require a certain degree of warmth only for a short period; for others, a more moderate warmth is sufficient, if it be of longer duration. The birch and the pine afford an example of this difference. The former tree does not put forth its leaves till the temperature has risen to about 53 or 54 degrees; and in all places where the mean summer heat falls short of this, the birch cannot flourish, however great may be the mildness of the winters. Such is the case on the island just mentioned, and in other parts of Lapland. The pine, on the contrary, requires a long rather than a warm summer. In the interior of Lapland, where the summer, though short, is warm, the birch rises much nearer the line of perpetual congelation than the pine; but in the Alps and other high chains in lower latitudes, where the summer is of longer continuance but colder, the pine is seen after the birch has entirely disappeared.

The frigid zone contains but few species of plants, yet of these the vegetation in summer is extremely rapid. The verdure of those countries, which lie within the polar circle, is confined chiefly to the hills having a southern aspect, and the trees are of very diminutive growth. Besides mosses and lichens, there exist ferns, creeping plants, and some shrubs yielding berries of an agreeable flavour. The arctic regions of Europe are peculiarly favoured; for, in certain parts of Lapland, there are

* Humboldt's Personal Narrative, vol. i.

fine forests, and even rye and leguminous plants are produced.

In the high latitudes of the northern temperate zone are the pine and the fir, which show their adaptation to a cold climate by retaining their verdure in the midst of the rigours of winter. To these, on advancing southward, succeed the oak, the elm, the beech, the lime, and other forest trees. Several fruit trees, among which are the apple, the pear, the cherry, and the plum, grow better in the northern half of this zone; while to its most southern part especially belong the more delicate fruits, such as the olive, the lemon, the orange, and the fig; and, amongst trees, the cedar, the cypress, and the cork.

The space, comprised between the 30th and the 50th parallels of latitude, may be considered as the country of the vine and the mulberry. Wheat extends as far north as the 60th degree; oats and barley a few degrees further. In the southern part of this zone, maize and rice are more commonly cultivated.

The vegetation of the torrid zone is characterised by a wealth, a variety, and a magnificence, which are nowhere to be found in the other regions of the globe. Under the beams of a tropical sun, the most juicy fruits and the most powerful aromatics arrive at perfection; and innumerable productions supply the wants and administer to the luxuries of man. There the grounds yield the sugar-cane, the coffee-tree, the palm, the bread-tree, the pisang, the immense baobab, the date, the cocoa, the vanilla, the cinnamon, the nutmeg, the pepper, the camphor tree, &c. &c. In South America, is the remarkable tree called the *cow-tree*, which, when incisions are made in its trunk, yields abundance of a glutinous and nourishing milk*. There are also various sorts of dyewood, and several species of corn peculiar to hot climates; while this zone is not destitute (in its elevated tracts) of every kind which grows in the plains of temperate countries.

* Humboldt, in the 4th vol. of his *Personal Narrative*, has given an account of this tree. The fecundity of nature in the torrid zone strikingly appears, when we consider the circumstances under which this vegetable milk is produced. "On the barren flank of a rock grows a tree with coriaceous and dry leaves. Its large woody roots can scarcely penetrate into the stone. For several months of the year, not a single shower moistens its foliage. Its branches appear dead and dried; but when the trunk is pierced, there flows from it a sweet and nourishing milk. It is at the rising of the sun that this vegetable fountain is most abundant. The Blacks and natives are then seen hastening from all quarters, furnished with large bowls to receive the milk, which grows yellow, and thickens at its surface."—*Personal Narrative*, vol. iv, pp. 216 and 217.

Under the equator, the climate best suited for the culture of all kinds of European grain lies between the altitudes of 6000 and 9000 feet above the level of the ocean. Wheat will seldom form an ear below the elevation of 4500 feet, or ripen above that of 10,800. With respect, however, to the lowest height at which corn can be raised between the tropics, there are great irregularities, which tend to prove that the augmentation of heat is not prejudicial to its cultivation, unless attended with an excess either of drought or of moisture. In the environs of La Victoria, a town of Venezuela (lat. 10½° N.), fields of corn are seen mingled with plantations of sugar-canes, coffee, and plantains, at the height of not more than from 1700 to 1900 feet above the sea. The district of Quatro Villas, in the interior of the island of Cuba, furnishes a still more remarkable example; there, fine harvests are raised almost at the level of the ocean. In nearly the same latitudes, on the other side of the Mexican Gulf, the fine fields of wheat are generally between 3800 and 7700 feet of elevation; while on the slope of the mountains of Mexico and Xalapa, vegetation, even at the height of 4320 feet, is so luxuriant, that wheat does not form ears. It is erroneous to suppose that grain degenerates in advancing towards the equator, or that the harvests are more abundant in northern climates. On the contrary, it has been found that nowhere to the north of the 45th parallel of latitude is the produce of wheat so considerable, as it is on the northern coasts of Africa, and in America, on the table-lands of New Grenada, Peru, and Mexico*. Near the town of La Victoria above-mentioned, the average produce is three or four times as great as that of northern countries. It is equally large at Buenos Ayres in the 35th degree of south latitude.

The vegetable forms near the equator are in general more majestic and imposing, and the varnish of the leaves is more brilliant. The largest trees are adorned with flowers larger, more beautiful, and more odoriferous than those of herbaceous plants in our zone. It is scarcely possible for an inhabitant of temperate regions to picture to himself the beauty and the grandeur of the vast forests of equinoctial America. Trees which attain a stupendous height and size are covered with

* The mean temperature for three months of summer is, in the north of Europe, from 59° to 66°; in Barbary and in Egypt, from 80½° to 84°; and within the tropics, at between 8950 and 3940 feet of height, from 57° to 78°.

profusion of climbing plants, and the same lianas as creep on the surface of the earth reach the tops of the trees, and pass from one to another at the height of more than a hundred feet. By this continual interlacing of parasite plants, the botanist is often led to confound the flowers, the fruits, and leaves which belong to different species. M. Humboldt gives the following striking description of the woods on the banks of the Cassiquiare, on approaching the point where that river branches off from the Oroonoko. "The luxurians of the vegetation increases in a manner of which it is difficult, even for those who are accustomed to the aspect of the forests between the tropics, to form an idea. There is no longer a beach: a palisade of tufted trees forms the bank of the river. You see a canal 200 toises (426 yards) broad, bordered by two enormous walls, clothed with lianas and foliage. We often tried to land, but without being able to step out of the boat. Toward sunset we sailed along the bank for an hour, to discover, not an opening (since none exists), but a spot less wooded, where our Indians, by means of the hatchet and manual labour, could gain space enough for a resting-place for 12 or 13 persons."

A large proportion of the trees of these majestic forests are more than 100 feet in height; while some, especially of the palms, have an elevation of 150 to 200 feet*. Various instances are recorded of the enormous growth of trees in tropical climates. Humboldt measured on the banks of the Atabapo, a bombax ceiba more than 120 feet high, and 15 feet in diameter. Near the village of Turmero, which lies to the south-west of the city of Caraccas, is the famous *Zamang del Guayre*, a species of mimosa, known throughout the province for the great extent of its branches, which form a hemispherical head more than 600 feet in circumference. The height of its trunk is about 63 feet, and its thickness between nine and ten. The branches extend like an immense umbrella, and bend towards the ground, from which they remain at an uniform distance of 12 or 15 feet. The circumference of this head is so regular, that M. Humboldt traced different diameters, and found them 204 and 198 feet in length. The dragon-tree (*dracæna*) at Oratava, in the

island of Teneriffe, is another specimen of enormous growth. Its trunk is about 50 or 60 feet high, and its girth near the roots almost 48 feet. Its average girth is stated by M. de Borda to be 35 feet, 9 or 10 inches. The baobabs are of still greater dimensions than the above. At Senegal, and in the islands of Cape Verd, some were remarked which had a circumference of from 56 to 60 feet, and in another part of Africa one was seen whose diameter was 34 feet (more than 100 in circumference.)

The distribution of plants cannot be explained solely by the influence of climate or by the distribution of temperature; for it frequently happens that similar climates are found in different parts of the globe without identity of productions. The climate of the high mountains of the torrid zone is analogous to that of our temperate zone; yet Humboldt did not discover one indigenous rose-tree in all South America, and it also appears that this shrub is entirely wanting in the southern hemisphere. The genus *erica* (heath) is quite peculiar to the Old World; of the 137 species known, not one is to be met with in the new continent. They seem to be very rare even in Asia. On the other hand, the *cactus* (Indian fig) is confined to the New World. It is true that a similarity exists in respect to their vegetation between very distant countries, where the physical circumstances are alike; but in some instances it is only a general resemblance of the vegetable forms. In many cases the same *genera* recur; but there are comparatively few examples in which identical *species* have been recognized in countries far remote from each other*. Species of pine, beech, elm, &c., are found in America, differing, however, from the Asiatic and European species. "The lofty mountains of equinoctial America (says M. Humboldt) have certainly plantains, valerians, arenarias, ranunculuses, medlars, oaks, and pines, which from their physiognomy we might confound with those of Europe; but they are all *specifically different*." The Antarctic birch (*betula Antarctica*) of Tierra del Fuego corresponds to, but does not exactly resemble the dwarf birch (*betula nana*) of Northern Europe.

According to Humboldt, the species of plants at present known amount to 44,000. Of these, 6000 are *cryptoga-*

* Such is the force of vegetation exhibited by American plants in every zone, that in the latitude of 57° N., on the same isothermal line with St. Petersburg and the Orkney Islands, the Canadian Pine (*Pinus Canadensis*) displays trunks above 150 feet high, and more than six feet in diameter.

* For an explanation of the terms *genus* and *species*, see page 59.

*mous**. The remaining 38,000 *phanerogamous*† plants are thus distributed :—

In Europe	7000
Temperate regions of Asia	1500
Asia, within the tropics and islands	4500
In Africa	3000
Both the temperate regions of America	4000
In America, between the tropics	13,000
New Holland, and the islands of the Pacific	5000

He also states the proportions of plants which grow in latitudes 0° , 45° , and 68° , to be as the numbers 12, 4, and 1. The mean annual temperatures in these latitudes are respectively $81\frac{1}{2}^{\circ}$, $55\frac{1}{2}^{\circ}$, and $32\frac{1}{2}^{\circ}$, and the mean summer temperatures $82\frac{1}{2}^{\circ}$, 70° , and $53\frac{1}{2}^{\circ}$. Within the tropics, the *monocotyledonous*‡ plants are to the *dicotyledonous*§, as 1 to 6; between the latitudes 36° and 52° , as 1 to 4; and at the polar circle as 1 to 2. The *annual* *monocotyledonous* and *dicotyledonous* plants in the temperate zone amount to one-sixth of the whole *phanerogamous* class; in the torrid zone they scarcely form one-twentieth, and in Lapland one-thirtieth part. A circumstance worthy of remark is the extreme rarity of the *social* plants between the tropics, that is, of those plants which, like the heath of Europe, live together and cover large tracts of land||. In the torrid zone, they are found only on the sea shore and upon elevated plains.

Among the vegetable forms there are some which become more common from the equator towards the poles, as the ferns, the heaths, and the rhododendrons; others, on the contrary, increase from the poles to the equator, among these are the *rubiacæ*¶, the *euphorbiæ*, and the leguminous plants; while others, such as the *cruciferae*** , the *umbelliferae*††, &c., attain their maximum in the temperate zone, and diminish towards the equator and the poles. The vegetable forms present (under the same *isothermal lines*) such constant relations, that

* Having neither blossoms nor visible fructification.

† Having visible organs of fructification.

‡ Having only one cotyledon or *seed-lobe*.

§ Having two *seed-lobes*.

|| Through Jutland, Holstein, Hanover, Westphalia, and Holland, a long chain of hills may be traced, entirely covered with common heath, and the *erica tetralix*. Very little success has attended the efforts made by the farmers to oppose the inroads of these plants.

¶ One of Jussieu's natural orders of plants, so named from *rubia* (madder).

** An order of plants, so named from their petals, four in number, being disposed in the form of a *cross*.

†† Having an *umbella* or *umbel*. This term is used to designate a particular mode of flowering, which consists of several flower-stalks, or rays, nearly equal in length, spreading from a common point or centre. The flowers of the hemlock and parsley are *umbellate*.

when upon any point of the globe we know the number of species belonging to one of the great families, both the whole number of *phanerogamous* plants, and the number of species composing the other vegetable families, may be estimated with considerable accuracy.

It has been a question discussed among philosophers, in what way the various vegetable tribes were originally diffused over the surface of the earth. Three different hypotheses have been maintained upon this subject. The *first* supposes that there was only one primitive centre of vegetation; all species of plants having had their existence originally confined to one tract of the earth, whence they were gradually dispersed over all countries.

This hypothesis was adopted by the celebrated Linnæus. He imagined the habitable world to have been at the commencement limited to one spot, in which were collected the originals of all the species of plants, together with the first parents of all animals and of the human race. As such various natures would require a diversity of climates for their support, he supposed this tract to have been situated in a warm region, and to have contained a lofty mountain range, between the base and the summit of which were to be found all temperatures and climates, from the temperature and climate of the torrid to those of the frigid zone. Linnæus endeavoured to support this hypothesis by referring to the means which are provided for the multiplication and dispersion of plants. Winds, rivers, and marine currents, are all, more or less, instrumental in the conveyance of seeds from one country to another. The former carry the lighter kinds of seeds to immense distances, and the two latter sometimes transport others from the most remote parts. The naturalist just mentioned remarks that the *Erigeron Canadense* was first introduced into the gardens near Paris from Canada; the seeds being scattered by the wind, this plant was, in the course of a century, spread over all France, Italy, Sicily, Belgium, and Germany. The migration of plants by means of currents is also well ascertained, and many instances of it are recorded. On the shores of the Hebrides are collected at times the seeds of the *mimosa scandens*, *dolichos urens*, and several other plants of Jamaica, the isle of Cuba, and the neighbouring continent. These are not the only methods in which the dispersion of species is effected: it is also known that some seeds (as the

misseltoe and juniper) are capable of preserving their vitality in the stomachs of birds, and are thus propagated. Lastly, man has introduced various plants into countries where they previously had no existence.

The *second* hypothesis is, that each species of plants originated in and was diffused from a single primitive centre; but that there were several of these centres situated in different parts of the globe, each centre the seat of a particular number of species. The *third* and last hypothesis is, that wherever a suitable soil and climate existed, there the vegetable tribes sprang up; and that plants of the same species were, from the first, spread over different regions.

We proceed to relate some facts which have been observed, and which will enable us to form some opinion as to which of the three preceding hypotheses has the best foundation. The greater number of these facts are taken from the opening part of Dr. James Prichard's work, entitled "Researches into the Physical History of Mankind," where they are brought forward in a similar discussion to the present.

Those plants whose structure is the most simple are found to be very generally diffused. Among the cryptogamous tribes, (such as mosses, lichens, &c.,) which form the lowest order of the vegetable creation, the same species are often met with in the most distant regions*. Two-thirds of the lichens observed in Australia, are also natives of Europe; and of the ferns of New Holland, which constitute rather more than 100 species, twenty-eight have been discovered in other countries. Many of the monocotyledonous tribes are also widely spread. Several grasses are common to Europe and Australia. In South America too, not only the mosses, but likewise several grasses, are the same as European species. It is not so, however, when we view the distribution of the more perfect, or of the dicotyledonous plants, there being a very small number of such, which are common to countries distant from each other. With respect to the dicotyledonous tribes, Humboldt has maintained that all the

indigenous kinds in those parts of America visited by him are peculiar to that continent, and that the only exceptions to this rule are plants of the sea-coasts, the migration of which is easily to be explained. The observations of Mr. Brown on the botany of Terra Australis (*Southern Land*) tend nearly to the same point. Of the plants already known in that country, 400 species are cryptogamous, 860 monocotyledonous, and 2900 dicotyledonous. Of the 400 cryptogamous, more than 120, that is nearly *one-third* part, are also indigenous in Europe. Of the 860 monocotyledonous, only 30, or about *one twenty-ninth* part, have been found in Europe, and more than half of these are grasses and *cyperoids*. But of the 2900 dicotyledonous species, only 15, or about the *one hundred and ninety-third* part, are the same in Australia as in Europe. Results no less striking have been obtained on comparing the vegetation of other southern countries with that of Europe and the northern regions. Though the proportion of European plants in Australia is so small, it appears to be greater than that which is observed in the south of Africa. The proportion of European species in South America is probably still less than it is in Southern Africa.

From the preceding remarks, it is to be gathered, that the most simply organized tribes of plants are very widely dispersed; that plants of the more perfect or more complex forms are, on the contrary, limited to particular countries; and that the monocotyledonous, which may be considered as tribes of an intermediate class, are neither so extensively spread as the former, nor confined within such narrow limits as the latter.

Some exceptions to this general rule have lately been brought to light by the botanical discoveries made during the expedition to the river Zaire on the west coast of Africa (about 6° S. lat.) From Mr. Brown's observations upon upwards of 600 plants collected in the neighbourhood of that river, it appears that about one-twelfth of the collection consists of species, which are also met with either in India, or on the opposite shores of Guyana and Brazil; and it is a curious fact, that in this number the *more perfect plants are in the greatest proportion*. This apparent anomaly is probably to be explained by the transportation of seeds from one shore to another by means of currents in the inter-tropical seas. Mr. Brown remarked that most of

* To explain the extensive diffusion of these species, Linnaeus supposed that their seeds, being invisible particles, might be carried to incalculable distances by the winds. It may, however, be remarked, that in the less perfect tribes of plants, the specific distinctions, not being so strongly marked as in the more complex forms, may escape detection; and thus two plants found in distant places may be set down as of the same species, when there is really some minute difference between them.

those plants in the African collection which are also natives of other countries, were seen only on the lower parts of the river Zaire, where they bear but a small proportion to the whole vegetation; and that most of the dicotyledonous species are such as produce seeds capable of retaining the germ of life during a long immersion in the waters of the ocean.

It will be proper in this place to mention the phenomena belonging to the vegetation of islands. In small islands the most remote from continents the species of plants are very few, and sometimes quite peculiar. Thus in Kerguelen's land, or the island of Desolation, when visited by Captain Cook, the whole flora was found to contain only 16 or 18 plants, all of which were considered to be peculiar to the island. Not a shrub was seen in the whole country. The flora of islands, as far as it is not peculiar to them, generally consists of the same species which grow on the nearest main lands. The different groups seated in the great Southern Ocean which lies between America and Eastern Asia serve as an example; the easternmost islands contain more plants of American families or species, and the western, of those tribes peculiar to India. Islands placed in the neighbourhood of two continents comprise the vegetation of both. Malta and Sicily have plants which belong to Europe, and others of an African stock. The vegetation of the Cape de Verd islands is intermediate between the flora of the Canary isles and that of the African coast.

The facts which have been introduced in the course of this inquiry forbid us to adopt the hypothesis of Linnæus, which considers all plants to have originated from one common centre. The propagation of the several tribes of plants has certainly taken place from a number of different points; since, of various parts of the world, separated by vast distances, each possesses a vegetable kingdom in a great measure peculiar to itself. The third hypothesis to which we alluded is equally untenable; since it is seen that plants are confined to particular tracts, till their seeds are conveyed elsewhere. Numerous instances have occurred in which plants by transportation have acquired a new country, and there become abundant; a striking example of this kind is the dispersion of the *Erigeron Canadense* over Europe, which we have already related. This shows that in the first instance plants of the same species were not produced in all regions possess-

ing a soil and climate suitable for their growth. We have also seen that, when the same species are observed to exist in countries widely separated, the circumstances generally are such as authorise us to infer that they were dispersed from one point. The only hypothesis which remains, and which is reconcileable with all the phenomena observed, is, that the vegetable creation was originally divided into different provinces, and that each country (probably each principal range of mountains) had its peculiar tribes which, at first, existed nowhere else. This conclusion is strengthened by the circumstance of particular plants having an entirely local and insulated existence, growing naturally on some particular mountain, and nowhere else. The cedar of Lebanon is one among several examples of plants of this description. Such instances alone might be deemed conclusive in favour of the hypothesis for which we have been arguing.

On the distribution of Animals—their original dispersion from distinct centres.

In the ascent from the vegetable to the animal world, and from one rank of animal existence to another, the most admirable order is manifest. We are not surprised by sudden steps or encountered by violent contrasts; an evident connection pervades the whole; and though there is a vast diversity when we compare the meanest specimen of organic life with its most perfect and majestic forms, yet between the two an harmonious chain may be traced, and we pass from one extreme to the other by a regular and scarcely perceptible gradation.

The lowest class is that of the *zoo-phytes* (plant animals), which raise up the coral islands spoken of in a former part of this treatise. They may be regarded as confused masses of beings, none of them endued with a separate life. Nevertheless, there is reason to believe, from the observations of MM. Péron and Lesueur, that each description of zoophyte has its place of residence determined by the temperature requisite for its support. The *mollusca*, whether naked or covered with shells (*testaceous*)*, possess each an individual existence, and of these it is unquestionable that different species belong to different countries. The pearl oyster arrives at perfection only in the equatorial seas.

* The term *testaceous* is in strictness applied only to such fish as have strong, thick, and entire shells; those which have shells, soft, thin, and consisting of several pieces joined together, as the lobster, &c., being called *crustaceous*.

Insects are the next in the scale of animal existence. In the midst of the exuberant vegetation of the torrid zone, the largest and the most splendid of these tribes are to be seen; the butterflies of Africa, of the East Indies, and of America, are adorned with the most brilliant colours; and in the tropical forests, especially those of South America, millions of shining flies present at night almost the appearance of an extensive conflagration. In these countries some races of insects exist in such multitudes, and are armed with such destructive or venomous qualities, as to enable them to lay waste the fruits of the earth through large tracts of country, or to become a source of the most serious personal annoyance and discomfort to man. The white ants (*termites*) raise lofty hillocks; and where they much abound, have been known to excavate the soil to such a degree, as to endanger the safety of houses which happen to stand above the seat of their operations. They devour paper and parchment so rapidly, that whole provinces of Spanish America (Humboldt informs us) do not afford one written document that dates a hundred years back. The *mosquitoes* and other species of the family of *tipulæ* are also formidable enemies to the human race in these climates. Amidst the forests of South America, especially along the banks of particular rivers, there are large tracts which are almost uninhabitable, owing to the thick swarms of these insects and the unceasing torment which they occasion. The lower strata of air to the height of nearly 20 feet from the ground are sometimes so filled with them as to give the appearance of a condensed vapour. During the day, the atmosphere teems with the *mosquitoes*, which are small venomous flies; these are succeeded, at night, by a species of gnats called *zancudoës*. The distribution of these insects is very remarkable, and frequently depends on local circumstances which cannot be explained. They are, in general, found to shun those rivers which have what the Spaniards call black waters (*aguas negras*), and also dry and unwooded spots. They swarm most upon the banks of rivers, and they nearly disappear where the elevation of the ground exceeds two or three thousand feet above the sea*. The annoyance occasioned by insects of this description is not confined to the torrid zone; for even in the Arctic regions of Greenland and Lapland, the

short heats of summer give birth to swarms of gnats of another species.

With respect to *fishes*, it is probable that every basin of the ocean has its particular tribes; while, indeed, the regions which some inhabit are well known. Thus the cod, which are distributed over all the northern seas between Europe and America, congregate chiefly upon the great sand-banks to the south-east of Newfoundland. The most remarkable species of fish are met with in the torrid zone and its vicinity. The flying fish hardly extends to any part of the ocean so high as the 40th parallel; but in the voyage to America, hundreds of them are seen by navigators after passing the tropic of Cancer. The largest and most powerful of those fish which possess electrical properties, also live within the torrid zone. The Mediterranean contains four species of electrical torpedoes; but the shocks which they communicate cannot be compared in violence to those of the *gymnoti* (electric eels), which inhabit several of the rivers, and also the stagnant pools, in the llanos of South America. All the inhabitants of the waters dread the society of these animals. It is related that, some years ago, it became necessary to change the direction of a road near Uritucú, in consequence of the number of mules of burden annually lost in fording a river in which the eels were very numerous. The temperature of the waters in which the *gymnoti* habitually live, is from 78 to 80 degrees: their electric force is said to diminish in colder waters.

The seas of the warm regions contain the shark, which is noted for its extreme ferocity; but the most enormous in size are the whale tribes, which belong more particularly to the high latitudes.

The migration of fishes seems to be occasioned by their seeking for shallow water, in order to deposit their spawn. The herrings, which are supposed to come from the bottom of the Arctic Ocean, proceed every year to the coasts of the British islands, Norway, Sweden, Denmark, Holland, and the United States; and also to those of Kamtchatka and the neighbouring islands. The opinion is, that their innumerable shoals follow the direction of the chains of submarine banks and rocks which they meet with in their progress. Tunnies also migrate regularly every year from the Atlantic Ocean to the Mediterranean.

The hot regions of the globe, and those of America in particular, contain

the largest and the most venomous of the order of *reptiles*, including the rattlesnake, and several other kinds armed with deadly poisons; and the boa constrictor, which destroys even the great quadrupeds by the force with which it coils round their bodies. Here, too, the lizard tribe, under the various names of crocodiles, gavials, alligators, and caymans, attain to an immense growth. The largest is the crocodile of the river Nile, which measures, when full grown, even thirty feet in length. It is worthy of remark, that the dry season near the equator has the same effect upon several of the reptile race as the cold of northern countries: in South America, when the swelling of the rivers subsides, and the surface of the llanos becomes parched by the heat, boas and crocodiles bury themselves beneath the mud, and await, in a state of lethargy, the periodical rains. As we proceed into the higher latitudes, reptiles diminish both in number and magnitude, and are, even the worst of them, comparatively harmless.

With respect to *birds*, we might at first be inclined to infer, from the powers of locomotion with which they are gifted, that the existence of each species is not limited to a certain region; and it is true that some of them, including several of the vulture tribe, spread themselves almost over the whole world. But it appears to be generally the case, that particular kinds are confined to a very small range, especially such as have heavy bodies and weak powers of flight. Even the *condor*, which frequently soars at an elevation of four miles, never forsakes the chain of the Cordilleras of Peru and of Mexico; and the great eagle does not quit the ridges of the Alps. The torrid zone possesses a variety of the most beautiful birds, including the humming-bird of America, the cockatoos, the bird of Paradise, the Lories, and several others of the parrot genus. The bird of Paradise is never met with beyond New Guinea and the neighbouring islands. Parrots, in the New World, are seen as high north as the 35th degree; but on the old continent, they do not appear to reach farther than the 28th parallel. Of the birds which cannot fly, each equatorial region insulated by the ocean has its particular kinds. The ostrich of Africa and Arabia, the cassowary of Java and of New Holland, and the Brazilian ostrich, are distinct species, possessing a general similarity of organisation.

The frozen zone, has its own kinds of

birds, among which are the *strix Lapponicus* (Lapland owl), and the *anas mollissima* (eider duck), which frequents the shores of the Arctic seas, and from whose nests the eider-down is obtained. The several species of *sea-birds* do not wander beyond certain limits assigned to each. The albatross is seen flitting along the surface of the waves, as we approach the 40th parallel of latitude. The sea-swallows and the tropical birds keep within the torrid zone. The penguin of the Northern differs from the manchot of the South Seas.

The migration of birds from one country to another, in consequence of the changes of the seasons, is a remarkable phenomenon. The direction and extent of these migrations are still, in most cases, but imperfectly known. On the approach of winter, swallows, storks, and cranes abandon the northern countries of Europe for the warmer climates of the south. In the equinoctial zone, which is nearly of the same warmth during the whole year, the variations of drought and humidity appear to influence the habits of animals in the same manner as the great changes of temperature in our climates. In South America, when the Oroonoko begins to swell with the rains, an innumerable quantity of ducks remove from eight and three degrees of north, to one and four degrees of south latitude, toward the south-south-east. These birds quit the valley of the Oroonoko at this period, doubtless because the increasing depth of the waters and the inundations of the shores prevent them from catching fish and insects. In the month of September, when the Oroonoko decreases and retreats within its bed, they return from the Amazon and the Rio Branco towards the north. The southern coasts of the West India islands also receive every year, at the season of the inundations of the great rivers of terra firma (the continent), numerous flights of the fishing birds of the Oroonoko, and of its tributary streams. It is in obedience to a similar instinct, that, during the heats of summer, the humming-birds advance in pursuit of insects into the northern parts of the United States, and even into Canada.

Quadrupeds are an order of animals more perfectly organised than any of those which have been under consideration; while, as they are in many instances immediately connected with man, and altogether come more under his observance, their distribution pré-

sents a more ample subject for investigation. The hot regions towards the equator furnish this order in the utmost number and variety; and many of its tribes are there distinguished for their size, their amazing strength, or the ferocity of their dispositions. The lion, the tiger, the elephant, the rhinoceros, the hippopotamus, the panther, the leopard, the hyæna, and the camelopard, are all inhabitants of the torrid zone and its vicinity. In the temperate regions, the animals are of much smaller dimensions; and the only beasts of prey are the wolf, the bear, the lynx, and the wild boar; but there the domestic tribes are reared in all their perfection. The white or Polar bear, which is quite different from the common bear and much more formidable, inhabits the coasts of the Arctic Ocean; so that, under both extremes of temperature, the animal creation assumes a character of excessive ferocity.

The *domestic* animals have been conveyed by man to various parts of the world, and are therefore very widely dispersed. Under this title are included the dog, the cow, the sheep, the goat, the horse, the ass, the pig, and the cat. Humboldt states (contrary to what has been supposed by some), that the cows in the equinoctial parts of South America will yield as rich a milk as in temperate countries. The ass is not capable of enduring cold so well as others of the domestic races: when beheld in the northern regions of Europe, he is quite a degenerate animal; south of the 40th parallel of latitude, under the influence of a more genial climate and better treatment, he is large, lively, and docile. The horse, originally a native of the central parts of the old continent, is now spread from the confines of the Arctic Circle to beyond the 50th degree of south latitude. It exists as high as Norway and Iceland, where it is small and of a peculiar variety, and extends even into the desolate regions of Patagonia. This animal was introduced into South America by the Spaniards, in their early visits to that continent; it has since greatly multiplied, and immense herds now rove wild over the *llanos*. The existence of these creatures is exposed to the most severe sufferings. "In the rainy season," says M. Humboldt, "the horses that wander in the savannah, and have not time to reach the rising grounds of the overflows of the rivers. The mares are

seen, followed by their colts, swimming, during a part of the day, to feed upon the grass, the tops of which alone wave above the waters. In this state they are pursued by the crocodiles; and it is by no means uncommon to find the prints of the teeth of these carnivorous reptiles on their thighs.

"We cannot reflect," he proceeds, "on the effects of these inundations, without admiring the prodigious pliability of the organisation of the animals that man has subjected to his sway. In Greenland, the dog eats the refuse of the fisheries; and, when fish are wanting, feeds on sea-weed. The ass and the horse, originally natives of the cold and barren plains of Upper Asia, follow man to the New World, return to the savage state, and lead a restless and painful life in the burning climate of the tropics. Pressed, alternately, by excess of drought and of humidity, they sometimes seek a pool in the midst of a bare and dusty soil, to quench their thirst; and at other times flee from water, and the overflowing rivers, as menaced by an enemy that encounters them on every side. Harassed during the day by gadflies and mosquitoes, the horses, mules, and cows find themselves attacked at night by enormous bats*, that fasten on their backs, and cause wounds which become dangerous because they are filled with acariæ, and other hurtful insects. In the time of great drought, the mules gnaw even the thorny melocactus (melon-thistle), in order to drink its cooling juice; and draw it forth as from a vegetable fountain. During the great inundations, these same animals lead an amphibious life, surrounded by crocodiles, water-serpents, and manatees. Yet, such are the immutable laws of Nature, their races are preserved in the struggle with the elements, and amid so many sufferings and dangers. When the waters retire, and the rivers return into their beds, the savannah is spread over with a fine odoriferous grass; and the animals of old Europe and Upper Asia seem to enjoy, as in their native climate, the renewed vegetation of spring." It has been observed by Buffon, that the largest quadrupeds, such as the elephant, the rhinoceros, the hippopotamus, the camelopard, the camel, and most of the ox kind, are possessed exclusively by the old world. In America, the *fossil* remains of some

* In Brazil, in the province of Ciara, the bats cause such destruction among the cows, that rich farmers are said from this cause to be sometimes reduced to indigence.

large animals have been discovered; but of living species, there are very few of considerable bulk. It has also been remarked, that the tribes which are the most powerful and perfect in their structure belong chiefly to the old world; those of the new having, in general, a character of organisation which assigns them a lower rank in the scale of animated beings. Such carnivorous animals, for example, as have the greatest vigour and courage (among which are the lion, the tiger, and the hyæna) are confined to Asia and Africa. The American tribes which approach most nearly to these, are, in general, much more gentle and feeble than the African and Asiatic species. It must be admitted, however, that Buffon's assertion respecting the cowardice of the feline race of America must be taken with some limitation: for it appears that the jaguar will sometimes attack men; and, when assailed by armed numbers, he has been known to offer an obstinate resistance. The swiftest, as well as the most graceful and beautiful quadrupeds (the antelopes, for example) also chiefly belong to the old continent; while those kinds which are the most useful to man, including the goat, the horse, the ox, and the ass, were unknown in America till their introduction into that country by the Spaniards.

Confining our view to wild animals, we may divide the earth into a number of zoological regions or provinces, each of which is the residence of a distinct set of quadrupeds*.

The first of these provinces, if we commence from the north, is the Arctic region, which contains the white bear, the rein-deer, the Arctic fox, and other tribes common to both of the great continents. The circumstance of their being common to both continents, is accounted for by the communication which, during winter, is established between the shores of Asia and America by means of the ice, over which a passage from one to the other becomes practicable to such animals as are fitted to endure the intense cold of the circumpolar countries.

The northern temperate zone is divided by the ocean into two great districts. The same tribes are found to be spread from the western to the eastern parts of the old continent; but the quadrupeds which inhabit the temperate climate of America are peculiar races.

The equatorial region contains three extensive tracts, widely separated from

each other by the sea. These are the intertropical parts of Africa—of America—and of continental India. Each of the three tracts in question has a distinct nation of quadrupeds. The Indian isles, particularly the Sunda and Molucca islands, may also be considered as a separate region.

Beyond the Indian Archipelago is Papua, under which name it is usual to include New Guinea, New Britain, and New Ireland. These countries, with the islands which are formed by a continuation of their mountain chains, namely, the archipelago of Solomon's Islands, Louisiade, and the New Hebrides, together with the more remote groups in the great Southern ocean, may be regarded as one zoological province. It is remarked, that all this extensive region seems almost wholly destitute of native warm-blooded quadrupeds, except a few species of bats, and some small domestic animals in the possession of the natives.

The large region of Australia forms another zoological province, in which are contained many indigenous tribes of a very singular description; and, lastly, the southern extremities of America and Africa are each distinguished by the possession of peculiar races.

Of these several provinces, into which the animal world admits of division, none is peopled with so remarkable a stock of animals as Australia, including, under that designation, New Holland, and the adjacent islands to the southward. It possesses several entire genera of quadrupeds which have been discovered in no other part of the world; and it further deserves notice, that most of the tribes peculiar to New Holland, though on the whole very different from each other, have some striking characters of organisation common to all. It was assumed by Linnæus, that the great class of warm-blooded quadrupeds was, without exception, *viviparous* and *mammiferous*—two terms, the first of which denotes their production of their offspring in a living and perfect state; and the second, their being supplied with organs for suckling their young. On this latter account, it received the name of *mammalia*, by which it is known among naturalists. It appears, however, that, in New Holland, a tribe of warm-blooded animals has been discovered, to which that name is not applicable, because it is *oviparous* (that is, produces eggs), and is therefore unprovided with organs of the description above-mentioned. This curious tribe is, as far as our present knowledge extends,

* See Dr. Prichard's work, before mentioned.

quite confined to New Holland. Another remarkable tribe is the *marsupial*, which term comprises such as produce their young in an immature state, and keep them for a time attached to their bodies, chiefly in abdominal *bags* or *pouches*, given them by nature for that purpose. This tribe also is met with principally in New Holland. One genus of it, indeed, the opossum or didelphis, is peculiar to the warm parts of America, and some species of phalangers are seen in the Moluccas; but over the Australian regions there are distributed several genera of the marsupial order, comprehending more than 40 species. Among these are the wombat, the kangaroo-rat, the kangaroos, and the dasyuri or Australian opossums.

The didelphis, or American opossum, differs from the Australian opossum in several respects; one of which is the having a long prehensile or muscular tail, which serves as a fifth limb, and is of great use to animals which inhabit forests so extensive and lofty as those of Guyana*. In the same part of America there are other animals which resemble the opossum in this respect; these are the sapajous, a numerous tribe of monkeys, the ant-eaters, the kinkajou, and the hystrix prehensilis (prehensile porcupine). Herein we behold striking instances of the structure of animals being fitted to the nature of the country in which they reside. The monkeys of Africa and of India are distinguished by no such peculiarity, for in those parts of the world it is not requisite.

We have already mentioned that the new continent is, compared with the old, nearly destitute of the most powerful and perfect tribes of quadrupeds. In their place are found most of those singular races, in the formation of which the ordinary rules of nature seem most widely to have been relinquished. Such are the tribes which Cuvier has termed Edentes, or quadrupeds defective with respect to teeth, some of them being entirely destitute of those organs. Thus America contains the whole family of sloths, the ant-eaters, which are quite unprovided with teeth, and the armadillos, which have grinding teeth, but no tusks or cutting teeth.

That part of Southern Africa which extends beyond the tropic of Capricorn, forms quite a distinct zoological province, separated as it is by the intervention of the torrid zone, from the milder climates north of the equator. Accordingly the

* The phalangers of Australia and the Moluccas have the prehensile tail.

animal creation of this region assumes a character almost as peculiar as that which is displayed by its vegetation. Of the order termed Mammalia, Southern Africa contains several peculiar genera, which occupy various distances towards the north, according to the degree in which they are capable of enduring a hot climate. In many instances the same *genera* are found in this region as in temperate countries north of the equator; but it is particularly to be observed, that the southern *species* differ from the northern. Thus the quagga, the zebra, and some others of the horse kind, answer to the ass and the jiggetai of Asia. From the southern tropic to the Cape of Good Hope, the continent of Africa stretches into fine level plains, over which roam a great diversity of hoofed quadrupeds. Besides five of the horse genus, there are also peculiar species of rhinoceros, of the hog and the hyrax; and among ruminating animals, the giraffe or camelopard, the Cape buffalo, and several remarkable antelopes, as the spring-bock, the gnou, the leucophoe, and others.

The animals of the Indian Archipelago have in some respects a different character from those of continental India, and approach towards those of Africa. The Sunda isles are said to contain a hippopotamus—an animal which does not exist in the rivers of Asia. The rhinoceros of Sumatra resembles the African more than the Indian species, but is specifically different from both. It is the same with the crocodile tribe, which is divided into three sub-genera, the crocodile proper, the alligator or cayman, and the gavial. The alligator belongs to America—the gavial inhabits the Ganges, and probably other rivers in continental India—of the crocodile proper there are six species, of which some belong to Africa, others to the isles of the Indian ocean, and one is said to have been discovered in the West Indies. Among flying quadrupeds, the flying marmoset or lemur, is seen only in the islands of the Indian ocean; two species of flying squirrel, and two remarkable genera of the family of bats, also reside there; besides which some of the flying phalangers are supposed to belong to the Moluccas.

It will be proper, in the next place, to inquire more particularly into the manner in which the most numerous families of quadrupeds are distributed over different parts of the world. In this enumeration, it is of course not intended to include those animals which man has been the means of conveying from one country to another, whence the same species have

in some instances become scattered over the most distant parts of the earth.

Most of those animals which Linnæus comprised in his order *Primates*, inhabit warm or temperate climates. The two grand divisions of this order are the bat and the monkey tribes. The latter has been subdivided by Cuvier into two chief branches, very different from each other—the simiæ proper, which are confined to the old continent—and the sapa-jous, which are peculiar to America. The African simiæ are distinguished from the Indian; and most of their species are limited each to a comparatively small tract. In the island of Madagascar, no true simiæ exist, but in their place are the makis, a tribe of lemurs. Of the bat tribe, the rousettes or frugivorous (*fruit-eating*) bats, inhabit the Indian archipelago and Australia, and the vampires, or blood-sucking bats, nine species of which have been mentioned, are all peculiar to the hot parts of America. The most numerous genus of bats are the vespertiliones; some of these are very extensively dispersed, but this is not the case with the majority, and not one species is common to the old and new Continents.

The *feræ*, or carnivorous quadrupeds properly so termed, are extensively spread, although most of them belong to hot climates. Of the twenty-eight species of the cat kind, which have been enumerated, not one is the same in America and in the Old Continent; even the lynx of Canada is now believed to be a distinct kind from the European. The African species are generally confined to Africa, and the Indian to the eastern side of the Indus. The tiger is found only in Asia, extending as high as Chinese Tartary; but it is by far most common in India, living in ravines and jungles. Africa, although destitute of tigers, possesses panthers and leopards. The lion is most formidable in Africa, where there are two species, the Barbary and the Senegal; it is also said to belong to India, and it inhabits those parts of Arabia and Persia, which border on the Tigris and Euphrates from the Persian Gulf as far as Bagdad. The Arabian species is smaller than the others, and the males have no mane. The *cougar* or *puma*, a native of South and North America, which is sometimes called the American lion, is a very different animal from the real lion. Of the dog kind, several species endure an arctic climate, and are common to the high latitudes of both continents. The *lagopus* or *isatis*

(arctic fox) is found at Spitzbergen, and may be traced through the north of Asia to Kamtchatka, and thence to the shores of America, Hudson's Bay, and Greenland. The wolf and the *lycaon* (black fox) are also common to all the arctic countries. Others of the dog-kind require a warm or a temperate climate, and these occupy a limited space either in Asia, in Africa, or in America. The dog of the Falkland islands (*canis antarcticus*), which was the only quadruped discovered there, has by some been considered a separate species, while others have held it to be the same as a species which inhabits Chili.

The *pachydermatous* (thick-skinned) tribes, live only in warm or temperate regions. There exist two species of elephant, the Indian and the African. Of the rhinoceros there are several species, but none of them are possessed in common by Asia and Africa. Those with two horns inhabit southern Africa, those with one horn belong to India and China, and to some of the islands of the Indian Archipelago. In America, the only representative of these large pachydermatous animals is the tapir. The hyrax and the hog tribes do not extend into cold climates; the wild boar, which ranges further towards the north than any of his tribe, is spread over various parts of Europe, but is never seen to the north of the Baltic. The domestic hog, since its introduction into America, has run wild and formed large herds in that Continent.

Among ruminating animals, the goat, the antelope*, and the giraffe, or camelopard, are limited to the Old Continent; but of sheep, some peculiar species are possessed by America, as, for instance, the paco, which in its domestic state is called bicunua or vigionia, and is an inhabitant of Peru. The camelopard, which is so remarkable for its height, its swan-like neck, and its gentle disposition, is a native of southern Africa. The antelope, of which the species are very numerous, is almost confined to Asia and Africa, none of them being found in Europe, except the chamois and the saiga. They inhabit as well the torrid zone as those parts of the temperate zones which are not very remote from the tropics. The dromedary, or camel with one hump, is a native both of Africa and Asia; the two-humped or Bactrian camel, so called because it is supposed

* Several American species have been described which are considered to be nearly related to the antelope.

to have originally come from Bactriana, belongs to much more northern climates than the other: it lives in the Crimea and in central Asia, in countries where the winter is very severe. The llama, or guanaco, which has been named by some the camel of the New World, is a widely different kind from either of the preceding. The musk resides in the mountains of Asia, from Cashmere, along the Altai, to the mouth of the river Ameer. This animal is not seen in the New Continent, although there are tribes which bear a relation to it. Some species of the deer and ox inhabit very cold climates, and these have passed along the arctic regions from one continent to the other. Those which are unable to support such severe seasons, are confined to certain local tracts in either continent.

We shall conclude our inquiry into the distribution of quadrupeds, with the mention of some facts respecting the description of animals discovered in islands. Small islands lying at a great distance from continents are in general quite destitute of land quadrupeds, except such as appear to have been conveyed to them by men. Kerguelen's Land, the islands of Juan Fernandez, the Gallapagos, &c., are instances of this fact. Among all the fertile groups in the Pacific Ocean, dogs, rats, hogs, and a few bats, are the only quadrupeds which have been seen. The Indian isles near New Guinea, abound in oxen, buffaloes, goats, deer, cats, rats, hogs, and dogs; but, according to all accounts, none of these have reached New Guinea, the two latter excepted. In Easter island, the most remotely seated in the Pacific, there are no domestic animals, except fowls and rats, which are eaten by the natives.

The quadrupeds of islands situated in the neighbourhood of continents, are generally the same as those of the adjacent main-land. This remark may be made respecting the animals of the British and of the Mediterranean isles, as well as of those in Madagascar, and in the islands near New Holland. When in such islands any quadrupeds are met with, which do not exist in the neighbouring continents, they are usually distinct species which occur no where else, and either have always had a local existence, or have been entirely destroyed from the main-land.

There is thus reason to conclude, that islands in general derived their quadrupeds from the continents in the neighbourhood of which they are placed.

Having now stated the facts which relate to the distribution of the principal races of animals, it remains only to inquire what inference we are entitled to draw concerning the manner of their original dispersion over the earth: whether that dispersion took place from a single spot, or whether, as in the case of the vegetable tribes, it commenced from a variety of distinct centres.

The local existence of insects is so closely connected with that of the plants which not only yield them sustenance, but also, in many instances, furnish their only place of abode, that we might at once expect to find the same laws prevailing in the dispersion of this part of the animal creation, as in that of the vegetable tribes. This conjecture has been confirmed by positive researches. M. Latreille, by whom the subject has undergone a full investigation, states, that the whole or the greater part of the arachnides and insects which inhabit countries of similar soil and temperature, but widely distant from each other, consist in general of different kinds. All the insects and arachnides which have been brought from the eastern parts of Asia, under whatever latitude, are distinct from those of Europe and of Africa. It further appears, that with insects, as with plants, where the species are different, the *genera* are nevertheless often the same. In this manner, the entomology of America approximates to that of the Austral countries, and the east of Asia. The insects of New Holland are often of the same genera with those of the Moluccas, and the south-eastern parts of India; they show much affinity to those of New Zealand and New Caledonia, and, as just observed, include similar genera to those of America: yet the entomology of New Holland is, notwithstanding, marked by a peculiar character. A large number of insects are found near the Cape of Good Hope, which are unknown in other countries: M. Lichtenstein collected there between 600 and 700 species, of which 340 were ascertained to be entirely new.

In adverting to the dispersion of the various tribes which inhabit the waters of the ocean, including the marine mammalia, as well as fishes and molluscæ, it is to be remarked that, in the descriptions of these tribes, great vagueness and inaccuracy has long prevailed. Therefore it is that this department of the animal kingdom contains so many species which are said to inhabit indiscriminately all parts of the ocean. The common whale

(*ba'æna, mysticetus*) has been supposed to belong equally to the frozen seas of Spitzbergen and to those of the antarctic circle. The sea-calf (*phoca vitulina*) is reported by several writers to be a native not only of both circumpolar regions, but also of the seas of the torrid zone; while some have gone so far as to assert that it exists in the Caspian, and even in the fresh-water lakes of Baikal, Onega, and Ladoga. But the fact of such extensive dispersion of marine animals rests entirely on the authority of incompetent persons. The celebrated naturalists Lesueur and Péron, who personally collected and examined a vast number of marine species in the southern hemisphere, have come to the conclusion, that the arctic ocean does not contain one tribe, well known and described, which is not *specifically distinct* from those animals most analogous to it in the antarctic seas. This remark applies not only to the cetaceous and phocaceous tribes, but also to the lower departments of marine animals; and, descending through a variety of worms and molluscæ, even to the shapeless sponges of the antarctic waters, these naturalists assert that, among all this immense assemblage, not one species will be found which exists in the seas of the northern hemisphere. It further appears that those maritime animals, which possess little power of self-extension, prevail within very narrow limits. Each species of the family of *medusæ* is seen in abundance in particular districts, and occurs in no other place. It is the same with the numerous *testacea* which adorn the shores of the southern seas. The shores of Timor present a great multitude and variety of beautiful testacea; but not one of these extends so far as the southern coast of New Holland.

With respect to reptiles, birds, and quadrupeds, the facts already stated concerning their distribution are sufficient to show that different regions of the world are each in possession of peculiar kinds. Many entire genera are wholly confined to certain districts; but when, as it frequently happens, the same genus is discovered among the wild and native animals of two distant regions, to a communication between which natural obstacles are opposed, it is not the same *species* that inhabit both countries, but corresponding species of the same *genus*. Thus the American species of the cat kind differ from the African and the Asiatic; and the species of horse, ox, antelope, rhinoceros, and elephant, of Africa, are distinct from those of the same genera in Asia.

Under these circumstances, we can arrive at no other conclusion than that the first dispersion of animals, like that of vegetables, took place from divers points. It is probable that, at least, each of the great mountainous chains and table lands was originally furnished by the Creator with a stock of animals. The offspring of each species have since spread themselves to as remote a distance from the first spot of their existence as their locomotive powers, their capability of bearing changes of climate, or the absence of physical obstacles to their further progress, may have allowed them to wander.

On Man in his Physical Character—His universal Dispersion over the Earth—Unity of his Species—Terms Genus and Species explained—Varieties of the Human Race, and manner in which they may be accounted for—Influence of Climate.

THE physical character of man, although it be not such as to exempt its possessor from those laws of generation, of growth, and of dissolution, which prevail among the inferior tribes of animals, is nevertheless of a peculiar and pre-eminent kind. His organisation, more perfect and complex than theirs; his erect and noble aspect; his form, better suited for rendering obedience to the impulses of a rational and intelligent mind;—all essentially distinguish him from the brutes over whom he exercises dominion. Under such circumstances as these, it is not a little surprising that there should ever have existed naturalists who pretended to confound the human species with tribes of the lower animal creation.

In some respects it may appear that the organisation of man subjects him to great disadvantages: the extreme feebleness of the human frame at the first period of its existence; the slowness of its growth; the multiplicity of its wants; the variety of ills and infirmities to which through life it is exposed, have no parallel among the beasts of the field. Yet who that considers the present moral imperfection of man, can deny the good which results from these physical disadvantages inseparable from his condition? Endued with the strength of the lion or the elephant, or clothed with a skin impervious to cold and moisture, he would probably have remained sunk in selfish indolence, and ignorant of all the arts which embellish life. But the feeling of his wants and weakness has aroused faculties which would else have lain dormant in his mind—has, by uniting him to his fellows,

given rise to the most endearing ties and the most useful forms of society; and has so called forth his inventive resources, that he has, to a considerable extent, acquired the command and the direction of the powers of nature.

The researches of modern navigators have shown that the human race is spread nearly over the whole earth. It has been found in the midst of the most sultry regions, in the vicinity of the pole, and upon islands which a boundless ocean would have seemed to cut off from communication with the rest of the world. The islands of Spitzbergen and of Nova Zembla to the *north*, and Sandwich Isle, the Isles of Falkland, and Kerguelen's Land to the *south*, are the only countries of considerable extent which have been found entirely destitute of human inhabitants. In the north, the habitations of man stretch nearly to the 75th degree of latitude; while in the south a miserable race (that of the Petcheres) exists on the bleak and barren shores of Terra del Fuego. The oases, or islands of verdure, scattered over the sands of Africa, are also the seats of population. In one part of the world the human body supports a heat higher than that which makes ether boil; and, in another, a cold which occasions the congelation of mercury.

Notwithstanding the dissimilarities of structure and complexion which are observed upon comparing the natives of different countries, there are the strongest reasons to believe that the human race forms not only a single *genus*, but also a single *species*; or, in other words, that all the several varieties of men sprung originally from one pair of individuals. Though there exist independent grounds for this opinion (as will presently be shown), it is proper, before we proceed to a statement of these, to remark that the whole tenor of Revelation is against any other supposition.

We may discern in the difference between the means adopted for peopling the earth with the human race, and those provided for covering it with the inferior creatures, the traces of that wisdom which uniformly pervades the arrangements of Providence. Had there been, in the first instance, no more than one pair of each genus of animals, and one individual of each tribe of plants, and had these been called into being upon only one spot of the earth, large regions separated by wide seas and lofty chains of mountains from the country containing that single spot, would for ever have remained almost, if not entirely, destitute of plants and ani-

mals, unless at the same time means had been provided for their dispersion far more effectual than any which we behold in operation. To prevent a result so little in harmony with what appears to be the general system of the universe, each separate region of the globe was supplied with a distinct stock of plants and animals. But in the instance of the human race, such a plan of proceeding was not requisite. Man was endued with a constitution capable of accommodating itself to the greatest changes of climate, and with the power of inventing methods for protecting himself against atmospheric influence: he was also enabled, by the aid of the same power of invention, to transport himself over the most extensive seas and across the most formidable ranges of mountains. Furnished with these capabilities, his race was originally placed in only one spot of the world.

In order that the question may be fully understood, it is requisite to explain what is signified by the terms *genus* and *species*, of which frequent use has been made in the course of the present treatise. A race of animals, or a tribe of plants, marked by any peculiarities of structure, which from one generation to another have always been constant and undeviating, form a *species*; and two races are held to be *specifically distinct*, if they are distinguished from each other by some peculiarities, which, in the lapse of generations, the one cannot be supposed to have acquired, or the other to have lost, through any known operation of physical causes: so that, under the word *species*, are comprised all those animals which are concluded to have sprung, in the first instance, from a single pair*. The term *genus* has a more extensive application. There are several species which so resemble each other as immediately to suggest the idea of some near relation between them. The horse, the ass, the zebra, and others of the horse kind, are one instance of this remark; the different species of elephants are another; and a third is furnished by the several kinds of oxen, buffaloes, bisons, &c., all belonging to the ox genus, and bearing a striking resemblance one to the other. As no physical causes are known which could have operated so as to produce those differences of structure, which exist between the several species of one genus, it is concluded that they origin-

* It is certainly possible that what we term one species may have sprung from two or more original pairs *exactly alike*; but, judging from all that has been observed, it is by no means probable.

ally sprung from different individuals. A *genus*, consequently, is a collection of several species on a principle of resemblance; and it may, therefore, comprise a greater or less number of species, according to the particular views of the naturalist. It is not, however, always easy to determine what races of animals are of the same, and what of separate species. It is a well known fact, that considerable varieties arise within the limits of one species; and such varieties are often transmitted to the offspring, and become, in a great measure, permanent or fixed in the race. Hence the difficulty, in some cases, of deciding whether two races of animals, of the same genus, and similar in many particulars, but differing in others, are merely what are termed *varieties* of one species, their diversities having proceeded from the action of external, or other causes, on a stock originally the same, or tribes of an entirely distinct origin from the beginning.

Dr. Prichard, in an able work entitled "Researches into the Physical History of Mankind," to which we have before had occasion to refer, mentions the criteria which may be used in order to determine whether all the races of men belong to the same species. The first of these is furnished by a reference to the general laws of their animal economy: since, should it appear that, in two races of animals, the duration of life is the same; that their natural functions observe the same laws; that they are subject to the same diseases, and susceptible of the same contagions—there is a very strong presumption that they are of the same species. Another way of examining the subject, is, to inquire whether the diversities in mankind are strictly analogous to those varieties in form, colour, &c., which occur in the lower departments of the animal creation, within the limits of the same species. The method, however, which bears most directly upon the question, is to ascertain what is positively known respecting the springing up of varieties among the human race.

First, with respect to the laws of the animal economy, it may be inquired whether there are any peculiarities which distinguish one race of men from another, of such a description as to render it probable that they constitute distinct species. Certain writers have supposed that there is a difference between Europeans and some other nations, in the duration of life. It is not to be denied that savage nations are, in general, shorter lived than the inhabitants of civilized countries;

but this circumstance is sufficiently explained by their addiction to intemperate habits, and their constant exposure to fatigue and hardships. When they have not such disadvantages to contend with, their term of life seems to be as long as that of any other race of men. Several instances are cited, both of negroes in the West Indies, and of native Africans, having attained to a very advanced age; and among the natives of America, cases of longevity are far from uncommon. Humboldt mentions the name of a Peruvian who lived to the age of one hundred and forty-three, and who, only thirteen years before his death, was accustomed to travel on foot from three to four leagues daily. The Laplanders, again, are said to be rather remarkable for long life.

As to diseases, it seems an undoubted fact that all human contagions, and all epidemic complaints, exert their pernicious influence on every tribe of men, though the natives of particular climates suffer more than others. And as to constitutional complaints, the difference is only one of predisposition, and analogous to what is witnessed in different families in the same nation, some being constitutionally more liable to certain disorders than others. The constitution of the American is observed to be the most torpid, that of the European in general the most irritable.

The conclusion which results from the first method of inquiry, as will be more particularly seen by referring to the work above-mentioned, is, that the grand laws of the animal economy are the same in their operation upon all the races of mankind. The deviations which occur are not greater than the common varieties in constitution which exist within the limits of the same family. Here, then, is one strong presumption in favour of the inference that all men belong to one species; for it appears that, among animals, neighbouring species, so closely allied as to have often been taken for mere varieties of the same stock (as the wolf and the dog), differ materially in the laws of their animal functions.

The next mode of inquiry suggested, is, how far the diversities of complexion, figure, and stature, seen among the several races of men, are analogous to those varieties which, in the inferior animals, often occur without marking any specific difference, and, indeed, originate before our eyes within the limits of the same species. In this place we shall accordingly note the most remarkable instances of variety which appear in mankind.

One, and that the most obvious to common observers, is the *diversity of colour*. It is well known that there is a correspondence between the colours of the skin, the hair, and the eyes of individuals. With few exceptions, light-coloured eyes are joined to a fair complexion and light hair, but a relation of the colour of the skin to that of the hair is perhaps universal. The women of Barbary and Syria are said to be often very white, although they have black hair; but this is to be attributed to art, and careful protection from the sun. Dr. Prichard, taking the hue of the hair as the leading character, divides mankind into *three* principal varieties of colour, which he calls the *melanic*, the *xanthous*, and the *albino*. The first includes all individuals or races who have *black* hair; the second, those who have either brown, auburn, *yellow*, flaxen, or red hair; and the third, those who have *white* hair, and who are also distinguished by red eyes. "The *melanic* variety forms by far the most numerous class of mankind. It is the complexion generally prevalent; except in some particular countries, chiefly in the northern regions of Europe and Asia, where races of the *xanthous* variety have multiplied; and it may be looked upon as the natural and original complexion of the human species. The hair of the head, in the *melanic* races, is of various texture and growth, from the long and lank hair of the native Americans, to the fine crisp hair of the African negroes. The hue of the skin varies from a deep black, which is that of some African nations, to a much lighter or more dilute shade. The dusky hue is combined, in some nations, with a mixture of red, in others with a tinge of yellow. The former are the copper-coloured nations of America and Africa; the latter, the olive-coloured races of Asia. In the deepness or intensity of colour we find every shade or gradation, from the black of the Senegal negro, or the deep olive and almost jet black of the Malabars and some other nations of India, to the light olive of the northern Hindoos. From that we still trace every variety of shade among the Persians and other Asiatics, to the complexion of the swarthy Spaniards, or of European brunettes in general." Examples of the *albino* variety have been noticed in almost all countries. In Europe they are by no means uncommon; sixteen instances have been seen in Germany by Professor Blumenbach. The fact of their occurrence in other parts of the world

is also fully established. It appears that they are frequent among the copper-coloured native Americans on the isthmus of Darien; and they have been observed in many islands both of the Indian and of the great Southern Ocean. Among the Hindoos they are regarded with peculiar horror. The most remarkable circumstance, yet not an unusual one, is the birth of white negroes among the black races of Africa: they are looked upon as curiosities, and are often collected by the native monarchs. Their hair is of a woolly character, and many of them are true *albinos*. The *xanthous* variety may be considered as intermediate between the other two. It chiefly prevails in the temperately cold regions of Europe and Asia, where it sometimes runs through whole tribes; but it also springs up out of every *melanic* race. The Jews, like the Arabs, are generally black haired, but many may be seen with light hair and eyes; and the same remark will apply to the Russians. The *xanthous* variety also appears among the South Sea islanders and the natives of America, and even among the negro races of Africa, both in their own climate and in the places to which they have been transported.

Varieties of form, more especially of the *shape of the skull*, furnish another grand instance of diversity among the races of men. The ingenious Professor Blumenbach has made the varieties in the construction of the skull the basis of a division of mankind into five principal races or departments, which he denominates, 1. the Caucasian; 2. the Mongolian; 3. the Ethiopian or Negro; 4. the American; and 5. the Malay and South Sea Island*. The *first* is that variety to which the nations of Europe and some of the western Asiatics belong; in this class the head is almost round, and of the most symmetrical shape, the cheek bones without any projection, the face oval, and the features moderately prominent. In the *second* class, the head is almost square, the cheek bones projecting *outwards*, the nose flat, the face broad and flattened, with the parts imperfectly distinguished, the internal angle of the eye depressed towards the nose. In the *third* class, the head is narrow and compressed at the sides; the forehead very convex, the cheek bones projecting *forwards*, the nostrils wide, the jaws lengthened, the skull in general

* The first three are the most strongly marked varieties in the form of the skull; the remaining two being only approximations to the preceding.

thick and heavy, the face narrow, projecting towards the lower part, the nose spread and almost confounded with the cheeks, the lips, particularly the upper one, very thick. The *fourth* variety approaches to the Mongolian: the cheek-bones are prominent, but more arched and rounded than in the skull of the Mongole, the form of the forehead and of the top of the head is often altered by means of artificial pressure during infancy, the face is broad without being flat, the forehead low, and the eyes deeply seated. In the *fifth* variety, the summit of the head is slightly narrowed, the forehead a little arched, the upper jaw somewhat projecting, the face less narrow, and the features more prominent and better marked than in the negro.

These descriptions give a clear idea of five principal varieties in the form of the human head; nevertheless, the attempt to assign them as the distinctive characters of so many races of men is open to strong objections; since, whether we take as a standard the figure of the skull, or perhaps any other peculiarity of structure, it is impossible, with reference to that standard, to divide the human species into departments, such as can be regarded with probability as so many separate races or families. The third, or Ethiopian variety of skull, is found in the greatest degree among the tribes inhabiting the coast of Guinea and other western countries of Africa; but it must not be set down as common among all the Negro nations; for there are many black and woolly headed races in Africa which come under the designation of Negro, who display a very different shape of the head and features from that described under the *third* variety. Again, the skulls of the New Hollanders are almost as much compressed as those of any Negroes, and they would, under the preceding classification, be brought within the Ethiopic race; yet no one could assert that the New Hollanders and the woolly-headed Africans, differing so much in other physical characters, and separated by so vast a distance, should be included in the same department of the human species. On this account, Dr. Prichard has proposed a division of the varieties of the skull into three classes, distinguished by names derived from their forms, and not from any supposed origin of the nations to which they respectively belong.

In the *shape of the body*, as well as in the *size and proportion of the limbs*,

and consequently in the degree of strength and agility which they possess, there are some remarkable varieties among nations. Some Negro tribes, the Australian or New Holland savages, and the Kalmucks, seem to be those which differ most in figure from Europeans. According to numerous measurements, the arm below the elbow is somewhat longer in the Negro, in proportion to the upper arm, and to the height of the stature, than it is in the European. It has therefore been remarked, that in this respect the generality of Negroes approach more to the structure of the ape; but if we descend to individuals, many Europeans will be found in whom the fore arm is as long as in the majority of Negroes, and, on the other hand, Negroes in whom it is as short as in the majority of Europeans. A clumsy form of the legs, broad and flat feet, and large hands, are also described as peculiarities of the Negro.

With respect to *stature*, the difference between one nation and another is generally not very considerable. From all accounts, the tallest race of men existing are the Patagonians. They are usually more than six, and, in some instances, as much as seven feet in height. On the contrary, the natives of Tierra del Fuego are described as miserable and puny savages. The Esquimaux, in the north of America, are likewise diminutive, being generally under five feet. Africa also contains some small races. Of the Bosjesmans or Bushmen, who are said to be the most deformed of mankind, Lichtenstein saw two individuals who were scarcely four feet high. This unhappy race, who were plundered of their property and hunted down like wild beasts by the early settlers in the Cape colony, have since lived among the rocks and woods on the northern frontier of the settlement, where they support themselves in a great measure by depredation. These instances tend to show that when whole races are deformed and stunted, it is to be attributed to exposure to constant hardships or an inclement climate, and to the wretched and precarious nature of their subsistence. Both extremes of stature which have been observed among nations, are frequently surpassed by individual examples in the inhabitants of different countries. Many natives of Europe, from eight to nine feet high, have been exhibited as objects of curiosity, and there have been dwarfs of less than four, and even three feet.

The only other varieties in the human

race which require notice, are those in the *texture of the skin*, and the *character of the hair*. The skin of Negroes is said to be always cooler than that of Europeans in the same climate, and to be distinguished for its sleekness and velvet-like softness. A similar observation has been made of several African tribes, and also of the Otaheitan. These qualities of the skin seem to be connected with the existence of the dark matter by which, among these nations, it is coloured; for in *albinos*, both African and Otaheitan, the skin becomes rough and inflamed, and cracks upon being exposed to the sun. The contrasts between the hair of different races are exceedingly striking. In the Negro, the Hottentot, and some other races, the hair is short and crisp, somewhat approaching to the nature of wool; in other nations it is long and lank; and between these two kinds there are numerous gradations. In Africa, the Kaffers have hair like that of the Negroes; some tribes have it longer; some again, who are black and otherwise similar to Negroes, have hair curled, but not crisp. The Papuas (the name by which the inhabitants of New Guinea and the neighbouring islands are distinguished) have crisp hair; but, unlike that of the Africans, it grows very long, and admits of being spread out into an immense bush. The hair of the natives of Van Dicmen's Land is as crisp as that of the Africans, but the New Hollanders have straight hair; while in the New Hebrides it is of an intermediate character, and varies considerably in the men of the same island. The hair of the natives of America is generally lank; in a few instances curled; but in none crisp or woolly.

In the next place, we shall compare the diversities, of which a sketch has been given, as existing in the appearance of the human race, with the variations in form, colour, and structure, which are seen in the lower animals, and especially in the domesticated kinds. The differences in colour which quadrupeds of the same species exhibit, are so familiar to the eye, that it is unnecessary to do more than allude to them. Among horses, oxen, dogs, cats, rabbits, &c., we continually behold hues which are analogous either to the melanic, the xanthous, or the albino varieties in mankind. Among several kinds of wild animals, a white not unfrequently springs up. In many instances, certain colours are prevalent in particular breeds, and

in some cases we might be warranted in concluding that the colours depend upon the local circumstances of the countries in which the breed is placed. Blumenbach mentions several examples which will illustrate this remark. He states that all the swine of Piedmont are black; those of Normandy, white; and those of Bavaria of a reddish brown colour. In Hungary, the oxen are of a greyish white; in Franconia, they are red. The turkeys of Normandy are black; those of Hanover almost all white. In Guinea, the dogs and the gallinaceous,* fowls are as black as the human race. Even in our own country, certain colours may be seen prevailing in the cattle of particular districts. Doctor F. Buchanan says, that in Mysore the sheep exhibit three sorts of colour: red, black, and white, and these are not distinct breeds. Don Felix de Azzara relates some curious circumstances respecting the colour of the horses and oxen in Paraguay, where, as well as in other parts of South America, both these races have run wild, and become very numerous. He says that all the *wild* horses are of one colour (a chestnut or bay-brown), whereas the domestic horses are of all colours, as in other countries. He makes a similar kind of observation concerning the oxen. As to form and the structure and proportion of parts, the diversities which arise in the same race of animals, far surpass those which subsist between one nation and another among men. Alluding to the hog tribe, Professor Blumenbach remarks, that "no naturalist has carried his scepticism so far as to doubt the descent of the domestic swine from the wild boar. It is certain that, before the discovery of America by the Spaniards, swine were unknown in that quarter of the world, and that they were first carried thither from Europe. Yet, notwithstanding the comparative shortness of the interval, they have in that country degenerated into breeds wonderfully different from each other, and from the original stock. These instances of diversity, and those of the hog kind in general, may therefore be taken as clear and safe examples of the variations which may be expected to arise in the descendants of one stock." He afterwards observes that the difference between the craniums of the Negro and of the European is not greater than that between the craniums of the wild boar and of the domestic swine. In the

* From gallus, a cock.

breeds of oxen, sheep, and horses, we may discern additional examples of deviation from an original standard. Some breeds of sheep and oxen are destitute of horns; others, on the contrary, are distinguished by the large size of their horns. In Paraguay there are breeds of oxen without horns, descended from the common horned race. With respect to horses, Blumenbach again observes that there is less difference in the form of the skull in the most dissimilar of mankind, than between the elongated head of the Neapolitan horse and the skull of the Hungarian breed, which is remarkable for its shortness and the extent of the lower jaw. The varieties in the covering of animals are not less worthy of notice than those to which reference has already been made. In the same race of sheep, some are clothed with wool, others with hair. It is known that if a flock is neglected, the fine wool is succeeded by a much coarser growth, intermixed with strong hairs; the breed, being no longer kept up with care, seems gradually to degenerate towards the characters of the *argali*, or wild sheep of Siberia, which naturalists consider to be the stock whence all domestic sheep have proceeded. A striking specimen of the changes which occur in breeds is afforded by the sheep of the West India islands, which, although descended from the woolly sheep of Europe, are covered with coarse hair. The deterioration has usually been attributed to the heat of the climate; but it must also be referred to the circumstance of their breed having been neglected. Other animals, such as goats and dogs, display a similar variety in the nature of their covering.

The preceding facts clearly prove that, in the lower animal creation, there spring up, *in the same species*, varieties of an analogous or similar kind to those which mark the different races of men. The existence of this analogy confirms still further the opinion expressed as to the unity of the human species. It now only remains to inquire whether it is absolutely known that varieties have arisen in a family or race of men similar to those diversities which distinguish one nation from another.

It is a well-attested fact that, among negroes and other dark-coloured tribes, individuals of the albino and xanthous complexions are not unfrequently born; and with respect to form and structure, and the texture of the skin and hair, many instances are recorded wherein

surprising peculiarities have made their appearance in a race or family, and some in which these have been transmitted to descendants. The description of such cases would exceed the limits of the present treatise; but an account of several may be seen by referring to the author* whom we already cited.

It appears, therefore, that if we apply to the subject under discussion the several criteria stated at the outset of this inquiry, the results, every one, lead to the inference that the various nations of the globe are descended from the same stock. This inference is drawn, *first*, from the observed uniformity in the grand laws of their animal economy, allowance, of course, being made for the effects of climate and of particular habits; *secondly*, from the existence in the same species among the inferior tribes of the creation, of varieties analogous to those which occur in mankind; and *thirdly*, from the fact of varieties being really known to have sprung up among men, more or less similar to those which distinguish different nations. There is, nevertheless, a point at which the similarity between the two cases obviously terminates: the peculiarities which arose in the human species at a remote and unknown period have become the characteristic marks of large nations, whereas those which have made their appearance in later times, have, in general, extended very little beyond the individuals in whom they first showed themselves, and certainly have never attained to anything like a prevalence throughout whole communities. But this is a circumstance which it does not seem difficult to explain, if we consider that, ever since the population of the world has been of large amount, the possessors of any peculiar organisation have borne such a very small numerical proportion to the nation to which they belonged, that it is no way surprising that they should soon have been lost in the general mass, still less that they should have failed to impress it with their own peculiar characters. In the early period of the world, when mankind, few in numbers, were beginning to disperse themselves in detached bodies over the face of the earth, the case was altogether different, and we can easily understand how, if any varieties of colour, form, or structure, then originated in the human

* Dr. Prichard's "Researches into the Physical History of Mankind."

race, they would naturally, as society multiplied, become the characteristics of a whole nation. These considerations may suggest to us the *manner* in which national diversities first obtained their ascendancy. The *causes* of those diversities are, and probably ever will remain, enveloped in mystery; and the inference as to the unity of the human kind is not weakened by our inability to assign those causes, since we are ignorant of the occasions even of the varieties which sometimes display themselves within the limits of a single family.

It will be seen, however, upon a comprehensive survey, that in the distribution of the different races of men there is a certain relation to *climates*. We may observe that the *black* races of men are principally situated within the torrid zone; and the *white* races in the regions approaching towards the pole; and that the countries bordering on the torrid zone are generally inhabited by nations of a *middle* complexion. It further appears that the natives of mountainous and elevated tracts are usually of lighter colour than the natives of the low and hot plains on the sea-coast. In Africa, most of the races between the tropics are either black or of a very deep colour; while beyond the tropics the prevailing complexion is either brown or red. The people of Fezzan, who are of a black hue, form an exception to this rule; but it has been remarked of them, that they are chiefly slave-dealers, and have been intermixed with the negro race brought from the interior of Africa. In other countries of the globe, the majority of the nations near the equator are almost black. In India there are black tribes in Malabar; and the Hindoos of the Deccan are generally very dark, as are also the inhabitants of Ceylon. In most of the islands of the Indian ocean, the *aborigines* are of a black colour; and still further eastward are the Papuas of New Guinea and the black inhabitants of Solomon's islands and the New Hebrides. In equatorial America, the natives are not so dark as in other parts of the torrid zone; but its elevated mountains, vast rivers, and extensive forests, impart a peculiar character to the climate of the New World, which may probably account for the difference. In the low countries of California it is remarked that the population are nearly as dark as negroes.

It is a very general opinion, that the

origin of the diversities of *colour* in mankind is to be referred entirely to the gradual influence of climate and of the sun's rays in darkening the complexion; it being a commonly-observed fact, that the skin, even of white men, becomes embrowned by constant exposure to the heat. But there are circumstances which militate against this opinion. There is positive testimony that the offspring of individuals, darkened by the sun in hot countries, is born with the *original complexion*, and not with the acquired hue of the parents*; besides which, it is known that white races of men, who have been removed from a cold to a hot climate, and have not intermarried with the natives, have retained for ages their original colour; while, on the other hand, black families, when transplanted into more temperate countries, have remained for generations of exactly the same hue as their African progenitors. Dr. Prichard has also remarked that the above supposition is contrary to a general law of the animal economy, according to which, *acquired* varieties† are not transmitted from parents to their offspring, but terminate in the generation in which they have had their origin.

Yet although it seems that the existence of varieties cannot be attributed to the slow and gradual operation of climate upon successive generations, numerous facts lead to the conclusion that there is a natural tendency among races, both of men and animals, to the production of varieties suited in form and constitution to the local circumstances of the country where they arise. Or it may, perhaps, be better explained, in some cases, by supposing that, whatever varieties occur, the ability to establish a footing in any country belongs to those only which possess a constitution adapted to local circumstances. Thus men of the *xanthous* variety of colour are known to spring up among the negroes in Africa; but their constitution being entirely unsuited to the climate, we cannot believe that they would ever become numerous in that continent. In the temperately-cold regions of the world they would be favourably circumstanced; and we accordingly see that this variety has multiplied there to a considerable extent.

* Dr. Prichard's "Researches," vol. ii. pp. 532, &c.

† *Acquired* varieties are opposed to those which a person brings into the world at his birth.











